Electrical Engineering

June
1939

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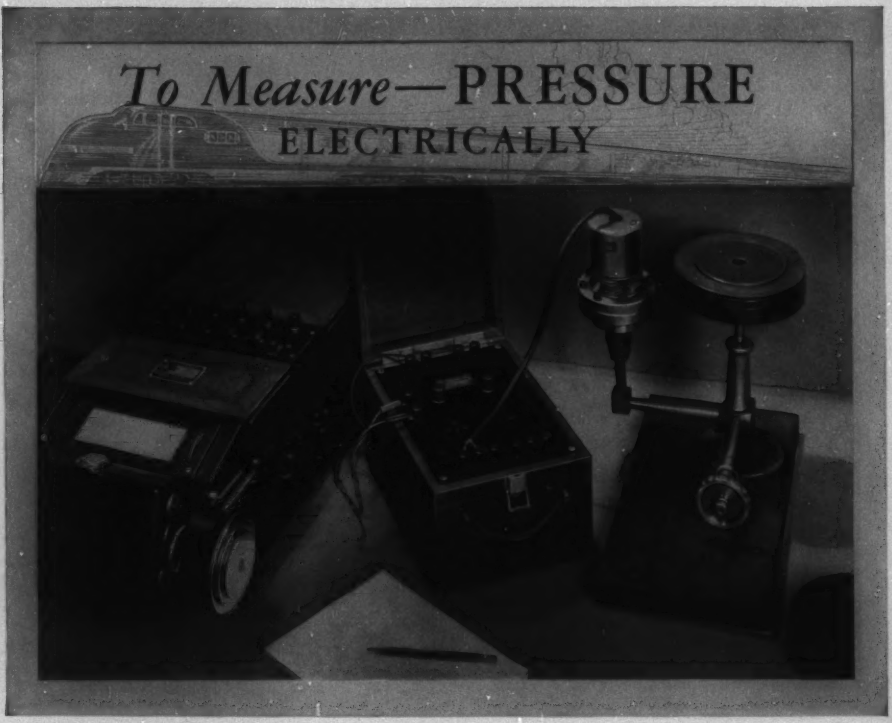
American Institute of Electrical Engineers

To Measure—PRESSURE ELECTRICALLY



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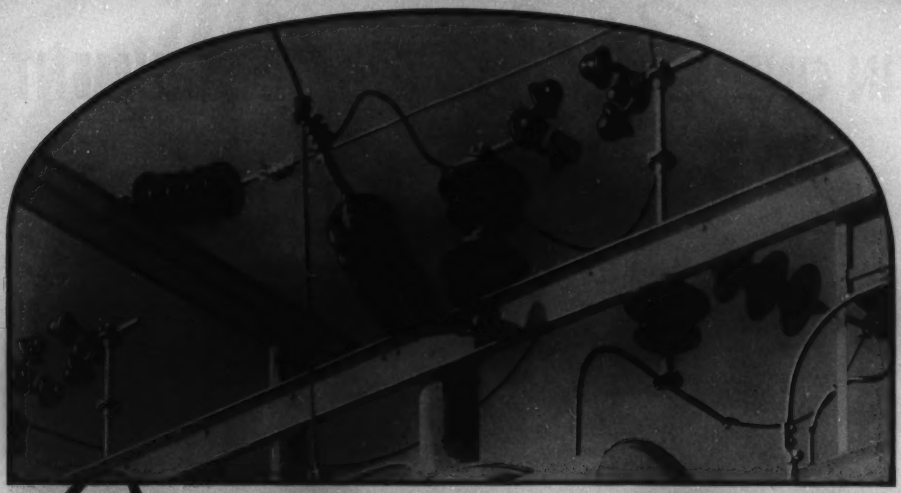
HEADQUARTERS FOR ELECTRICAL MEASUREMENT

GENERAL ELECTRIC

430-143



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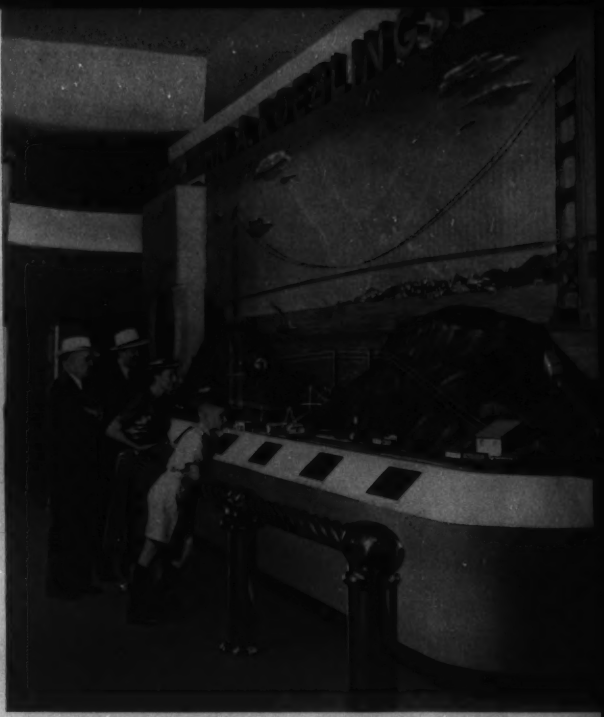

"I WANT YOU TO SEE THIS, JACK. It's that Roebling Passenger Tramway I was talking to you about. Somebody used his head when he put in these blueprints so engineers can study the construction details."

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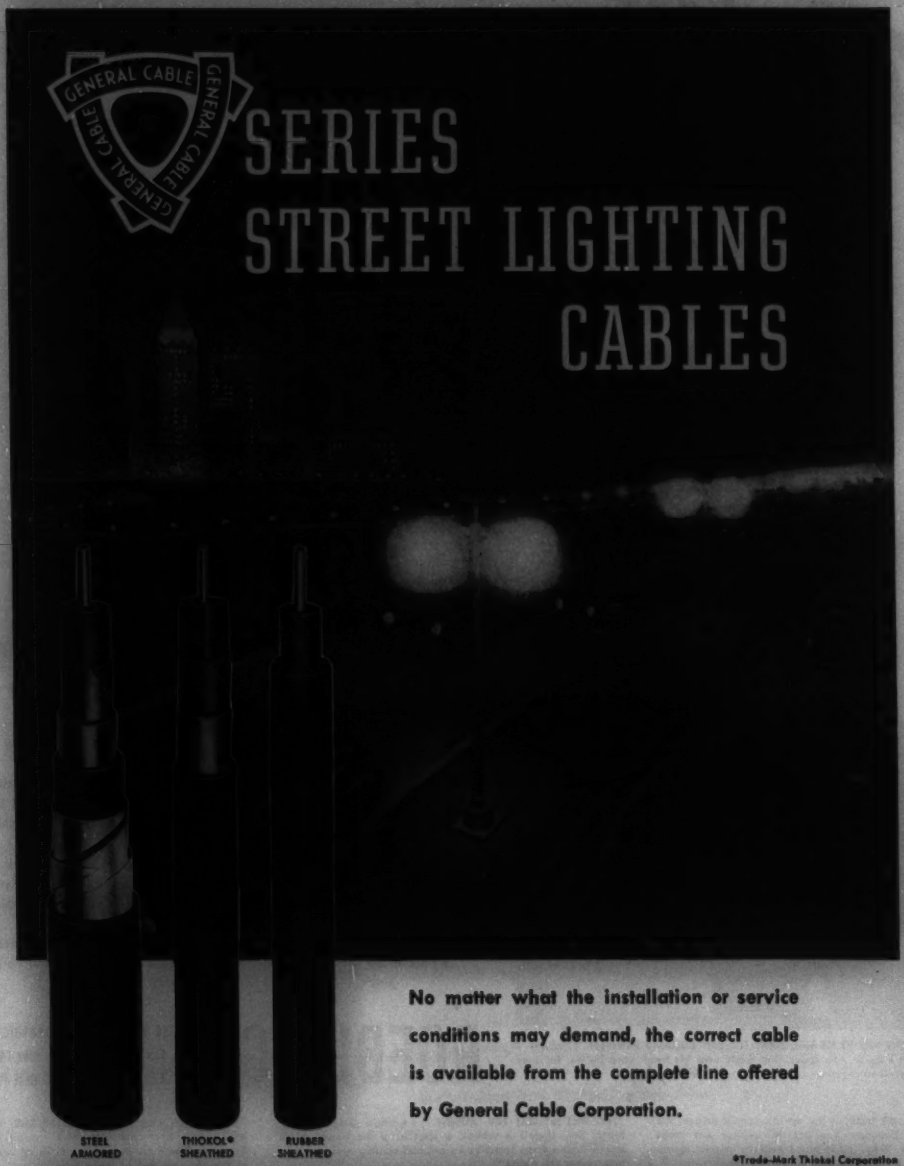

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Electrical Engineering

Registered U. S. Patent Office

for June 1939—

The Cover: One of the two Elephant Towers at the main entrance, and the 400-foot Tower of the Sun, at the Golden Gate International Exposition, a feature attraction of the AIEE combined summer and Pacific Coast convention to be held June 26–30, in San Francisco, Calif.

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VISIT THE BAKELITE EXHIBIT, HALL OF INDUSTRIAL SCIENCE, NEW YORK WORLD'S FAIR 1939

High Lights

Synthesis of Color. Exposition lighting on Treasure Island in San Francisco Bay will be one of the feature attractions of the Institute's forthcoming summer convention. Through the generous co-operation and collaboration of the General Electric Company and *Architectural Record*, ELECTRICAL ENGINEERING is able to present in this issue a group of four-color reproductions of effects created at the Golden Gate International Exposition through the masterly use of electrical illumination. Technical data and explanations have been drawn from the text of a technical program paper scheduled for presentation at the convention (*pages 234–50*).

Lightning Performance. An AIEE subcommittee has gathered data on the lightning performance of transmission lines operating in the United States and Canada at voltages from 110 kv to 165 kv, from which the benefits of various means of protection may be evaluated (*Transactions pages 294–306*).

Fiber Glass Insulation. Textiles woven from fibers of glass have some advantages over those from organic fibers and asbestos for use as electrical insulation. Operation at higher temperatures than can be withstood by organic fabrics is possible, up to limits imposed by the impregnant used (*Transactions pages 277–86*).

Asbestos and Glass Insulation. Magnet wire insulated with asbestos fibers has become well established by long use; recently wire insulated with glass fibers has been introduced for use where temperatures are high. Temperature limitations, however, must be studied in terms of many related factors (*Transactions pages 290–4*).

Mica Insulation. A mineral widely used for high-temperature insulation is mica, which may be split into films as thin as 0.0003 inch; thin films are assembled into large sheets with the aid of suitable binders. The solid, nonporous structure offers some advantages over other flexible inorganic materials (*Transactions pages 287–9*).

Thomson Commemorated. At a recent meeting of the American Philosophical Society, the memory of Elihu Thomson was honored by presentation of several papers, each dealing with a different phase of his life. His achievements as an electrical engineer were related by a prominent AIEE member (*pages 251–5*).

Bus Protection. Several recent experiences with faults on power-station busses have shown the desirability of relay protection, to which little attention had been given because of the assumed relative freedom from faults and the possibility of incorrect tripping. Differential relaying may be used (*Transactions pages 243–52*).

Battery Chargers. Air conditioning of railroad cars has increased greatly the demands on the car storage battery, and has made necessary the charging of batteries on standing cars from power circuits. Dry rectifiers of the magnesium-copper sulphide type with forced cooling have been built for this purpose (*Transactions pages 260–5*).

Standards. In an effort to acquaint the membership more fully with the standards activities of the Institute, the AIEE standards committee is sponsoring a series of articles. This month's contribution discusses the place of the International Electrotechnical Commission in electrical standardization (*pages 272–3*).

Modulators. Improvements in copper-oxide rectifiers have led to their use as modulators in carrier telephone systems, where they replace vacuum tubes; no power is required, but numerous effects are found that ordinarily are not important in the tube arrangements (*Transactions pages 253–60*).

Local AIEE Activities. A total of 635 Section meetings was reported to AIEE headquarters during the fiscal year just ended, the largest number ever reported; the number of Branch meetings was somewhat less than were reported during the two preceding years (*pages 268–71*).

Summer and Pacific Coast Convention. Final plans for the AIEE combined summer and Pacific coast convention are rapidly nearing completion, and the complete tentative technical program has been announced (*pages 268–71*).

Railway Relay Protection. Electrification of the Pennsylvania Railroad from New York to Washington, D. C., and Harrisburg, Pa., necessitated the solution of new problems in relays (*Transactions pages 266–77*).

District Meetings. Brief reports of the meetings held by the Institute's South West and North Eastern Districts appear in this issue. Both meetings included District student conferences (*pages 263–4, 266–7*).

Transformer Standards. Several departures from previous standards are involved in new proposed standards for transformers, regulators, and reactors (*Transactions page 289*).

Faraday Medal. W. D. Coolidge (A'10, M'24) recently received the Faraday Medal for 1938; he is the third American to be so honored since the medal was established in 1921 (*pages 258–62*).

Sound Measurements. Sound-level measurements at some 900 different locations provide useful information concerning the noise in residences, large business offices, and factories (*pages 255–7*).

Paper Prizes. National prize awards for papers presented at Institute meetings during 1938 have been announced (*page 271*).

Coming Soon. Among special articles and technical papers undergoing preparation for early publication are: an article on the electric strength of fibrous glass, by Andrew Gemant and F. A. Glassow; an article discussing synthetic insulating materials and their application to wires, by Winton Patnode, E. J. Flynn, and J. A. Weh; an article describing a bridge for separating the components of traveling waves, by H. E. Hartig (M'30) and Cledo Brunetti; an article on the calculation of terminal voltage of synchronous generators for various overexcited power factors, by S. H. Wright (M'34); a paper on electromagnetic-horn design by L. J. Chu (A'39) and W. L. Barrow (M'33); a paper describing an electronic control circuit for resistance welders by T. S. Gray (M'38) and J. Breyer, Jr. (A'38); a paper on cold-cathode gas-filled tubes as circuit elements by S. B. Ingram (M'38); a paper describing electric drives for supercalenders in paper mills by R. H. Smith (M'36); a paper describing a system of polyphase radiobroadcasting by J. F. Byrne (A'32); a paper on a reverse-rotation test for the determination of stray-load loss in induction machines by T. H. Morgan (M'31), W. E. Brown (A'39), and A. J. Schumer (A'39); a paper describing a 12-channel carrier telephone system for open-wire lines by B. W. Kendall (F'29) and H. A. Affel (M'23); a paper describing a simplified precision resistance-welder control by F. H. Roby (A'37); a paper on low-gas-pressure cable by G. B. Shanklin (M'29); and a paper on progress of a-c arc welding by C. J. Holslag (M'19).

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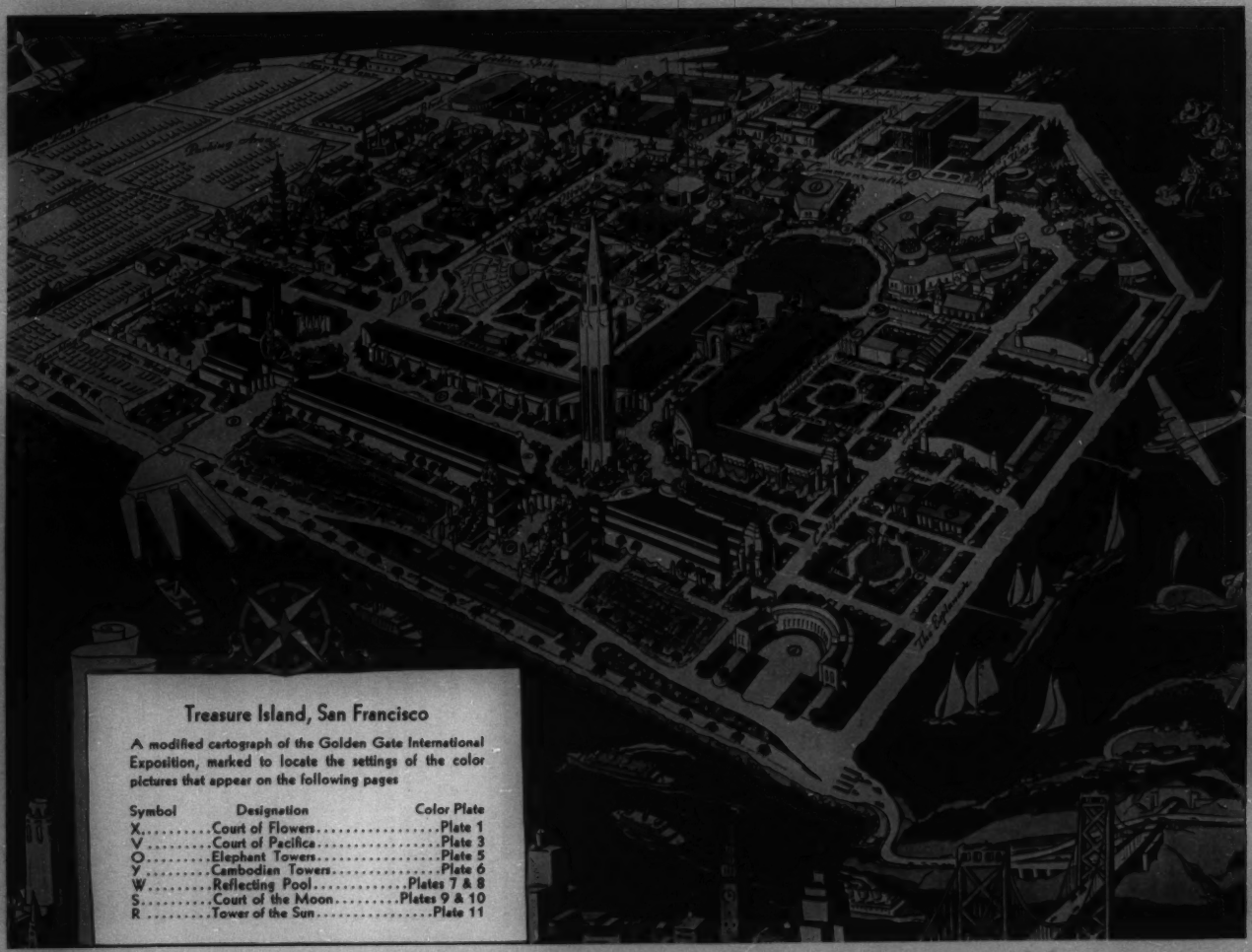


Treasure Island, San Francisco

A modified cartograph of the Golden Gate International Exposition, marked to locate the settings of the color pictures that appear on the following pages

Symbol	Designation	Color Plate
X	Court of Flowers	Plate 1
V	Court of Pacifica	Plate 3
O	Elephant Towers	Plate 5
Y	Cambodian Towers	Plate 6
W	Reflecting Pool	Plates 7 & 8
S	Court of the Moon	Plates 9 & 10
R	Tower of the Sun	Plate 11

PLATE 1: "Court of Flowers," Louis P. Hobart, Architect.

COLOR: NEW SYNTHESIS IN THE WEST

PLATE 2. One of the most dramatic aspects of the Golden Gate International Exposition (seen here from Yerba Buena Island) is the clear integration of the exterior illumination system with the architectural design. Note the careful organization of both colors and intensities, the visual sequences achieved thereby, the subdued and largely decorative role of street lighting.

COLOR, LIGHT AND STRUCTURE AT GOLDEN GATE EXPOSITION

by **A. F. DICKERSON,**
Director of Illumination*

Almost unnoticed, the rapid development of new illuminants and lighting equipments has, in the recent past, added a distinct and prodigious dimension to the field of exterior illumination—that of color. But precisely because the application of color to buildings is both a complex and unevenly explored field, available examples are few and often inconclusive. A notable exception is this year's Golden Gate International Exposition. Here—with a scale and completeness seldom approached before—is an artificial illumination system which is an integral part of the project design. Mr. Dickerson's paper thus not only describes an illumination project of interest to light specialists but constitutes reference material of prime value to building designers, engineers, and others. All photographs were specially taken by Gabriel Moulin for ARCHITECTURAL RECORD.

EACH OF THE great American expositions has marked progressive advances in the field of artificial illumination. Chicago's Columbian Exposition of 1893 startled the world with its wide use of the then-novel incandescent lamp. In 1915 the Panama-Pacific Exposition in San Francisco reached new levels in the use of exterior floodlighting. Chicago's Century of Progress showed further advances, particularly in the field of color. But it is safe to say that the current expositions employ a wider variety of new illuminants, equipments, and installations than all their predecessors combined. The Golden Gate International Exposition furnishes dramatic proof of such advances; and because the problems involved are applicable to all building design, description of its principal features seems worthwhile.

Daylight color: A standard palette of 19 colors and gold was adopted—with ivory, brown, gold and blues predominating. Seven colors are body or foundation colors; eight are used for embellishment of minor architectural features, four and gold for trim. Tints and shades, rather than pure colors, are employed throughout. All body colors are warm, with light intensities — yellow, ivory, fawn, ecru, taupe, brown, and blue; the secondary colors include yellow, jade (light and dark), emerald, four additional blues, red, mauve, and apricot.

In the majority of cases, this color was applied in pigment form in the plastered surfaces, in paint form on trim and detail. The plaster itself has an unusual luminosity, an effect achieved by pressing a mica product into plastered surfaces. The mica had first been heated to a high degree so that it became flaky and the laminations tended to separate. The result is a breaking up of the wall surfaces into innumerable small holes with a high reflective factor.

Night color: The artificial illumination must be understood as being superimposed on a base of the colors and surfaces described above. But the night color *does not seek to reproduce that of natural daylight.* On the contrary, many of the most successful effects are achieved solely with colored illumination on near-white surfaces. Compare, for example, the daylight and night colors of the Court of Pacifica (Pl. 3 and 4). Nor do the various *intensities, shadows, and silhouettes seek to duplicate those of natural daylight.* In fact, the illumination may be said to yield an additional —and entirely new—design over and above that of daylight.

The basic consideration in designing the illumination of the Exposition was to make it a truly integral part of the building design. Such integration of light and structure implied much more than mere concealment of the light sources, or avoidance of glare and shadows. That it has been achieved —and with spectacular success in installations such as that of the Court of the Moon (Pl. 9) and the Elephant Towers (Pl. 5)—is apparent. Here color achieves a luminosity which appears as coming from *within* the building rather than of being applied from *without.*

Once inside the bright exterior walls, the visitor moves through a series of color effects in a succession of walled courts—each lighted differently, with a harmony which makes the transition from one to another easy, yet distinct. In these courts, lighting has been used to fit the visitor psychologically to enjoy the setting. Emotions are excited toward gaiety by shades of red, rose, orange, and yellow—while greens, blue greens, and blues are used as tranquilizers. Colors are always in harmony and restricted in number from any viewpoint. Highlights, shadows, and silhouettes break up the monotony of the usual flatness of floodlighted surfaces. Advantage has been taken of every flag, niche, or unusual architectural element, to introduce a change of color or a highlight in order to increase the liveliness of the night scenes. Fountains throughout the grounds are illuminated, usually in static colors excepting in the Court of Pacifica (Pl. 3) where a shifting color cycle is controlled by thyratrons. In many places trees have been lighted by concealed mercury floodlights; but in general they count as dark masses against light.

Installations and fixtures: While the effect of the Exposition's illumination system may often appear extravagant, construction and operation were in fact relatively simple and inexpensive. All equipment is commercially available, including a weather-proof low-cost searchlight and a low-cost fluorescent floodlight, both of which were especially developed by General Electric for the Exposition. The various installations are in common use in ordinary commercial buildings: *floodlighting*—in trenches, set-backs, soffits, etc.; *spotlighting* of architectural features —towers, sculpture, niches, etc.; *groundlighting* by means of light standards and recessed fixtures; *water lighting* by underwater floodlights, lip lighting, etc. The chief interest here lies largely in demonstrating the extraordinary versatility possible with careful study at a sufficiently early stage.

But each of these installation types represents a high degree of specialization so that, when properly integrated, there is little need for supplementary lighting. This explains the relative unimportance of street-lighting units in the illumination design. In the major courts, these units serve more as architectural features than as sources of illumination. Outside the courts, street-lighting units of a more utilitarian character are used.

Illuminants: The range of lighting media includes all commercially available sources — incandescent, lumiline, arc, mercury- and sodium-vapor, neon, fluorescent, and ultra violet "black light" for use with luminescent paints. These media were used singly and in combinations, depending upon the colors, changes, and intensities desired. Quantitatively the most important were incandescent and fluorescent lamps — the specially developed fluorescent floodlights being widely used.

All illumination designs shown are by General Electric's Illuminating Laboratory.

*The overall design of day-and-night color is the end product of close cooperation between the following Exposition officials: W. P. Day, Director of Works; Jesse E. Stanton, Director of Color; Edward L. Frick, Chief of Division of Architecture; William R. Van Bokkelen, Chief of the Electrical Division; George E. Garthorne, Assistant Chief and in charge of Exterior Illuminations; the entire Architectural Commission under the chairmanship of Arthur Brown, Jr.; and Mr. Dickerson, Director of Illumination.

No novice in the field, Mr. Dickerson played an important part in the illumination of the Panama-Pacific Exposition of 1915, the Brazilian Centennial in 1922, A Century of Progress in 1933, and in floodlighting of Niagara Falls. Since 1932, he has been head, Illuminating Laboratory and Lighting Sales of the General Electric Company at Schenectady, N. Y.

PLATE 3. Vivacity is here achieved not only by a wide variation of color and intensity of light but also by its movement. Synchronized thyratron controls give smoothly changing yet steady emphasis to the two most important architectural features—the statue and the fountain. Backgrounds have even values and harmonized colors which silhouette the planting.

THE COURT OF PACIFICA

TIMOTHY L. PFLUEGER, Architect

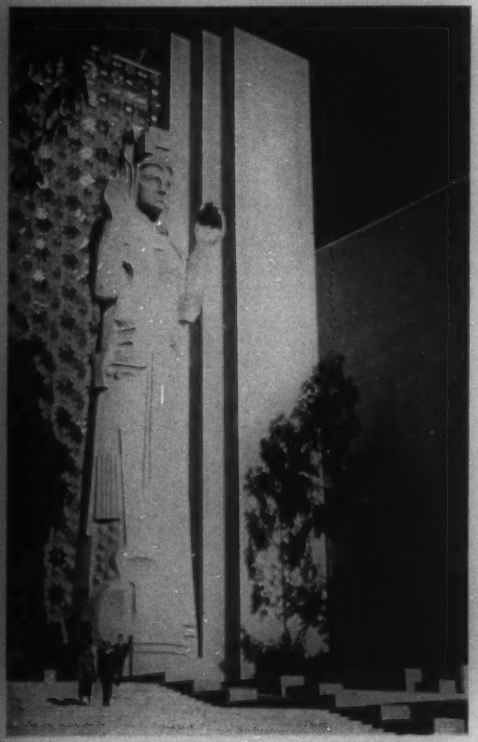


PLATE 4. This daylight view serves as a point of reference as regards the daylight-color base on which illumination is superimposed. All structures illustrated have similar colors and values.

FIGURE 1

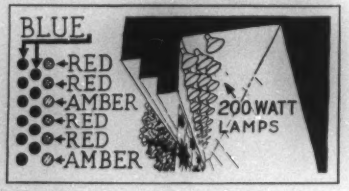


FIGURE 2

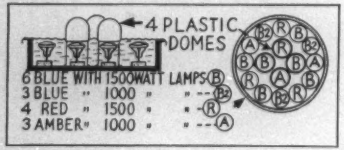


FIGURE 3

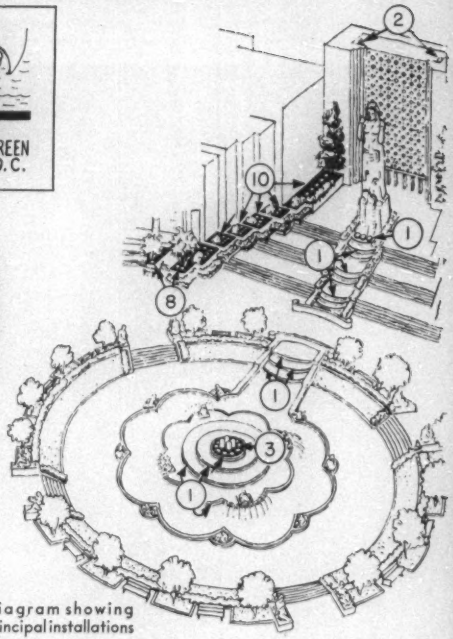


Diagram showing principal installations

THE DESIGN of this court, as well as its location adjacent to the most popular entrance to the Exposition, called for a lighting treatment tending toward the spectacular. The chief installations of the illuminating system are:

The Great Window with its stainless-steel screen and plaster backdrop lit by 75 amber, 150 red, and 300 blue 200-w. floods controlled by thyratrons. (Fig. 2);

Robert Stackpole's 85-ft. statue, "Miss Pacifica," lighted by two 1500-w. underwater floods (Fig. 1);

The cascades and central fountain, with lip lighting of green and changing colors from underwater floods where there are jets. (Figs. 1 and 3);

The 80-ft. walls flanking the Grand Stairs and also the walls of the East Entrance are flooded in a golden amber (similar to Fig. 10);

Sixteen 86-ft. cylindrical lanterns (not shown) of Glyptal-treated fabric shed a warm glow that completely envelopes the Court. Each lantern has three-hundred 60-w. lamps, or a total of 288 kws. is used for the 16 standards (design similar to Figs. 6 and 7);

All of the main trees are lighted with 250-w. mercury floods concealed in ground cylinders (Fig. 8);

The East Entrance and the Gayway Plaza are lighted by decorative units with tiers of amber-orange lamps and banners. This exposed lighting furnishes a transition to the Amusement Section. Approximately 550 kws. of lighting are used in this Court.

PLATE 5. Highest intensities and lightest colors have been widely used on those elements primarily designed to be seen from afar. Thus the brilliantly lit West Facade, with its monumental entrances, actually serves as a huge sign which dominates the city's eastern horizon and intersects its traffic lanes to the mainland. Colors are concentrated at the entrances.

THE ELEPHANT TOWERS AND WEST FACADE

ERNEST E. WEIHE, Architect

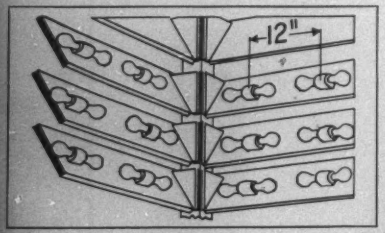


FIGURE 4

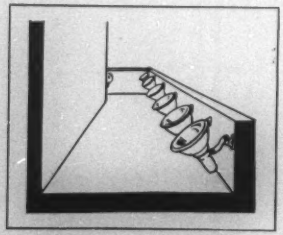


FIGURE 5

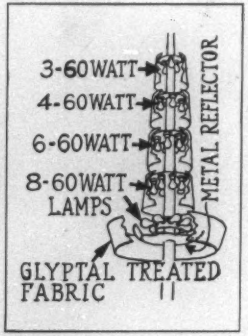


FIGURE 6

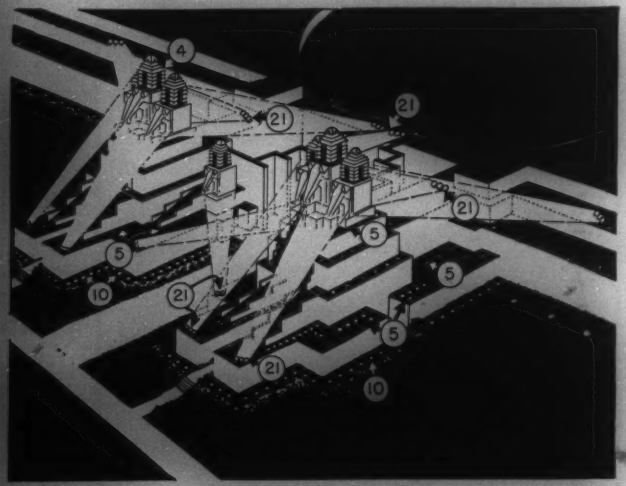


Diagram showing search- and floodlight locations for Towers and West Facade

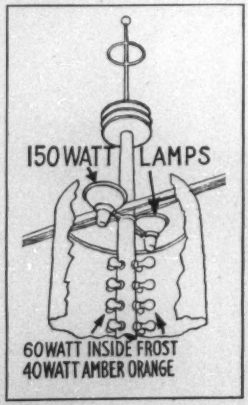


FIGURE 7

THE WEST FACADE, for its entire distance of 3600 ft. from the Administration Building north, is floodlighted in white with color reliefs at the South Tower, main Elephant Tower entrance, ferry entrance, and in the seven large green circles above the entrances. Thirty cylindrical lanterns, 50 ft. in height with 4920-w., and 102 similar small lanterns, 18-ft. high with 1620-w., add a festive note to this area. These lanterns are all steel framework on steel poles with decorated Glyptal-treated fabric as the transparency (Figs. 6 and 7).

The main wall is lighted by Novalux L-49 floods with polished Alzak-processed reflectors, asymmetric lenses and 500-w. I. F. MAZDA lamps. These are spaced on 10-ft. centers, 15 ft. from the base of the wall, in a specially provided trench that is completely concealed by trees and shrubbery. (Similar trenches of various widths are used for all floodlighting throughout the Exposition. See Fig. 10.) In general, illumination values increase with height (Pl. 5): on the first set-back 200-w. floods with etched reflectors and clear lenses are used on 8-ft. centers; 300-w. floods on 10-ft. centers light the second set-back (Fig. 5). The elephants themselves are picked up with 18-in. incandescent searchlights equipped with 1500-w. floodlighting lamps (Fig. 21). The louvered "howdahs" are in red, with 60-w. natural ruby incandescent lamps 12-in. o.c. (Fig. 4).

White light on the cream plaster yields surfaces whose values are approximately equal to those of daylight

PLATE 6. The richly textured golds of Lulu Braghetta's and Jaques Schnier's bas-reliefs are carried in pink, the towers in golden amber, while the set-backs are carried in lavender. Here, again, a brilliant lighting effect is adequately framed by quiet, unlighted water. Thus the scale and balance of daytime are maintained at night while new colors are introduced.

THE CAMBODIAN TOWERS AND EAST FACADE

WILLIAM G. MERCHANT, Architect

THE ENTIRE East Facade (to the right but not shown) is lighted in uncolored light in much the same manner as the West Facade. Trenches of 6-ft. width, completely concealed by shrubs and trees, house 500-w. asymmetric floods on 8-ft. centers for lighting walls (Fig. 10); the illumination of the set-back is provided by 200-w. floods. This lighting is broken by large standards at the building entrances and the East Towers and murals (Pl. 6) which form the East entrance to the walled city.

The Towers, rising from tiers of steps, are heavily ornamented in gold leaf and carried in golden light at night. The huge bas-relief gold-leafed murals are lighted by pink fluorescent floods concealed at their bases (Fig. 12), and similar installations light the set-backs in lavender. The terraces and stairs are lighted by Siamese umbrella-type units built of fabric. Trees in the center are floodlighted by 250-w. mercury-vapor lamps (Fig. 8). The lighting of flags and flag masts uses the same installation employed elsewhere (Fig. 9).

FIGURE 8

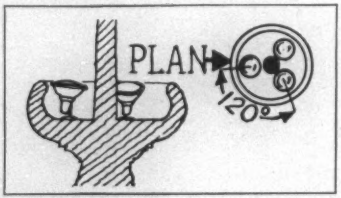


FIGURE 9

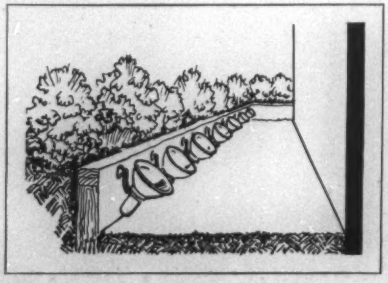


FIGURE 10

FIGURE 11. Luminescent murals used in the Court of the Seven Seas.

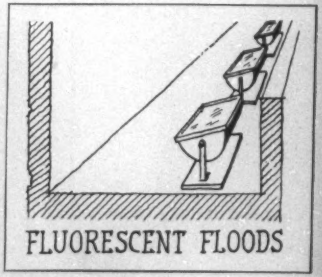


FIGURE 12

THE COURT OF REFLECTIONS
LOUIS P. HOBART, Architect

PLATE 7. Connecting the brilliant East Entrance (Pl. 6) and the Tower of the Sun (Pl. 11), the color and lighting levels of this court are adroitly handled. Walls and set-backs are lighted with pink fluorescent floods (Fig. 12), niches with blue fluorescent tubes (Fig. 22). The Arch is flooded from base and adjacent roofs with white 18-in. incandescent searchlights (Fig. 21).

PLATE 8. Looking west in the Court of Reflections towards the Tower of the Sun. As the name implies, water is here used as a reflecting medium to pick up and repeat the brilliantly lit Tower of the Sun. Elsewhere (Pls. 1, 10, and 11) water becomes part of the illumination system itself, adding not only color and movement but a considerable amount of light.

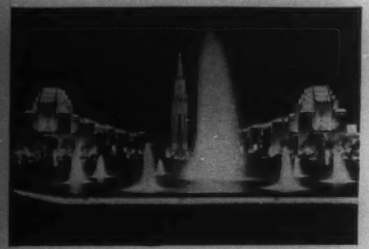
PLATE 9. Illumination of this Court is subdued, employing cool colors and low intensities. The main walls are carried in blue with a lavender overlay, while the set-backs are in blue; a mottled pink-and blue effect is used on the towers. All relief lighting—in grilles, niches, and louvers—is carried in amber to lighten the effect and tie it in with that of the other Courts.

THE COURT OF THE MOON

GEORGE W. KELHAM, Architect

HERE, AGAIN, illumination cannily implements both architecture and circulation: although physically one of the four major axes which radiate from the Tower of the Sun, this court is unimportant circulation-wise. The illumination is thus subdued, designed for relaxation, not for pulling heavy traffic. For the walls, 500-w. blue floods are used on 30-in. centers; in the same trench, pink fluorescent floods on 60-in. centers tint the blue to an orchid shade (Fig. 16). The crenelated set-backs are lighted with three 15-w. blue fluorescent floods (Fig. 15). Both blue and pink fluorescent floods are used on the tops of the towers for producing the striking mottled effect (Fig. 14).

Ground lighting is by downlights in ten units concealed in decorative elements of iron and Celoglas (Fig. 17). The other lighting features are: the 24 arches of water, lighted by seventy-two 250-w. amber underwater floods; the north fountain with its falling jets and cascades in amber (Fig. 13); mercury lighted trees; spot-lighted statuary; grilles and turrets in amber relief lighting.



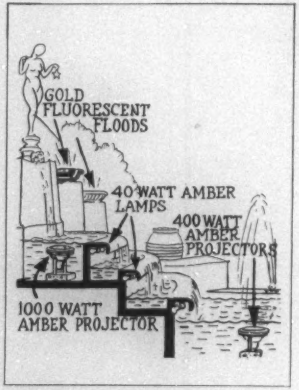


FIGURE 13

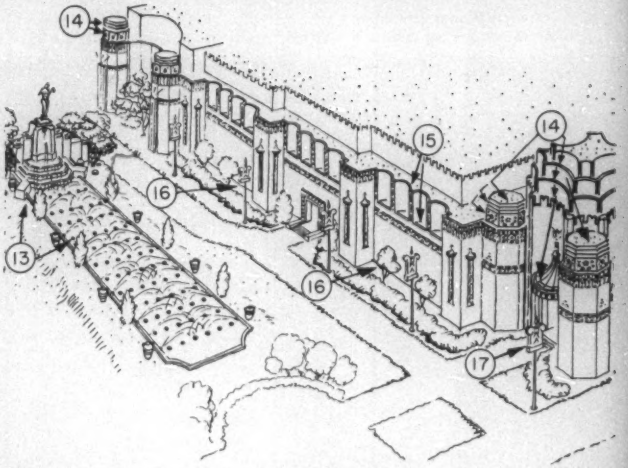


Diagram showing relationship of major installations in Court of the Moon

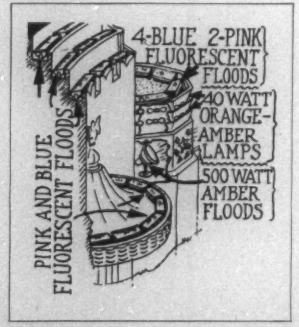


FIGURE 14

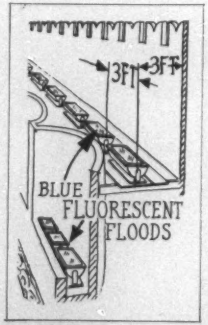


FIGURE 15

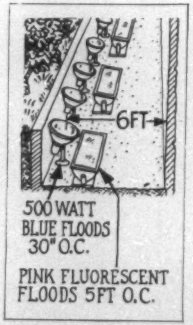


FIGURE 16

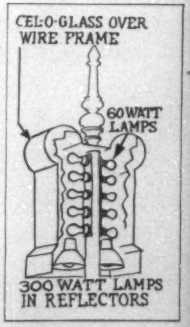


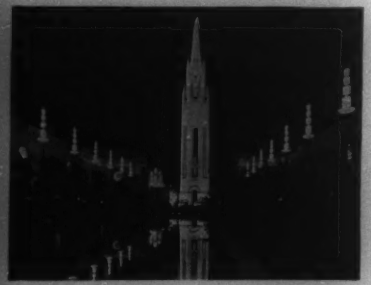
FIGURE 17

PLATE 10. The golden-amber floodlighting on both Cadorin's sculpture, "Evening Star" and the long pool save the lighting of the Court of the Moon from appearing too low or subdued in key — the 24 jets and the fountain itself give movement to the scene. Added color is achieved by the mercury-lit trees and the relief lighting in amber.

THE TOWER OF THE SUN

ARTHUR BROWN, JR., Architect

SINCE THE Tower of the Sun is the "theme center" of the Exposition, and since the Court of Honor in which it stands is consequently the most important traffic intersection within the Exposition gates, it was important that the night effect be at least as dramatic as that of daytime. This has been accomplished (Pl. 11) by concentrating light at high intensities on the Tower, which in turn lights the Court by reflection. The shaft proper is lighted by 56 white 1500 w. searchlights (Fig. 21), 24 amber and 24 white 1000 w. floodlights, and 60 amber 1000 w. floodlights (Fig. 20). A ring of twenty-four 500 w. concealed street-lighting units (Fig. 23) supplements the court lighting. Other features are: the four illuminated fountains (Fig. 1), the eight flags (Fig. 9), the four belvederes and the lighted trees (Fig. 8).



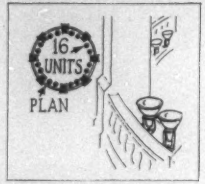


FIGURE 18

FIGURE 19

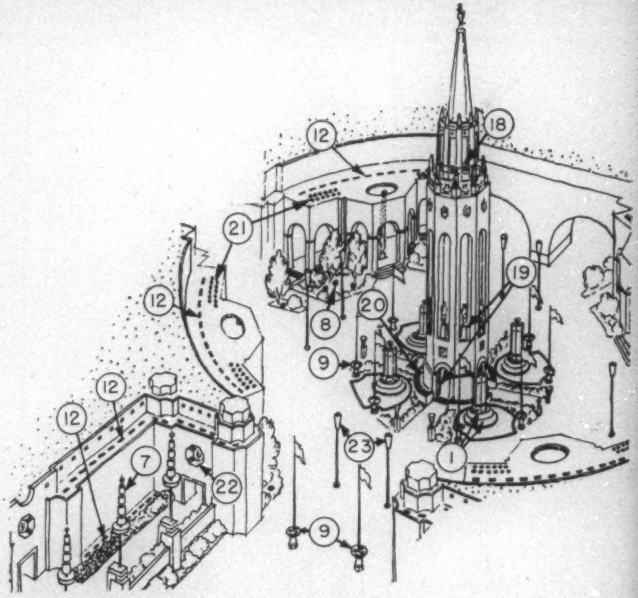


Diagram of all installations in Court of Honor and Tower of the Sun

FIGURE 20

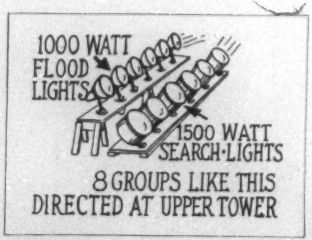


FIGURE 21

FIGURE 22

FIGURE 23

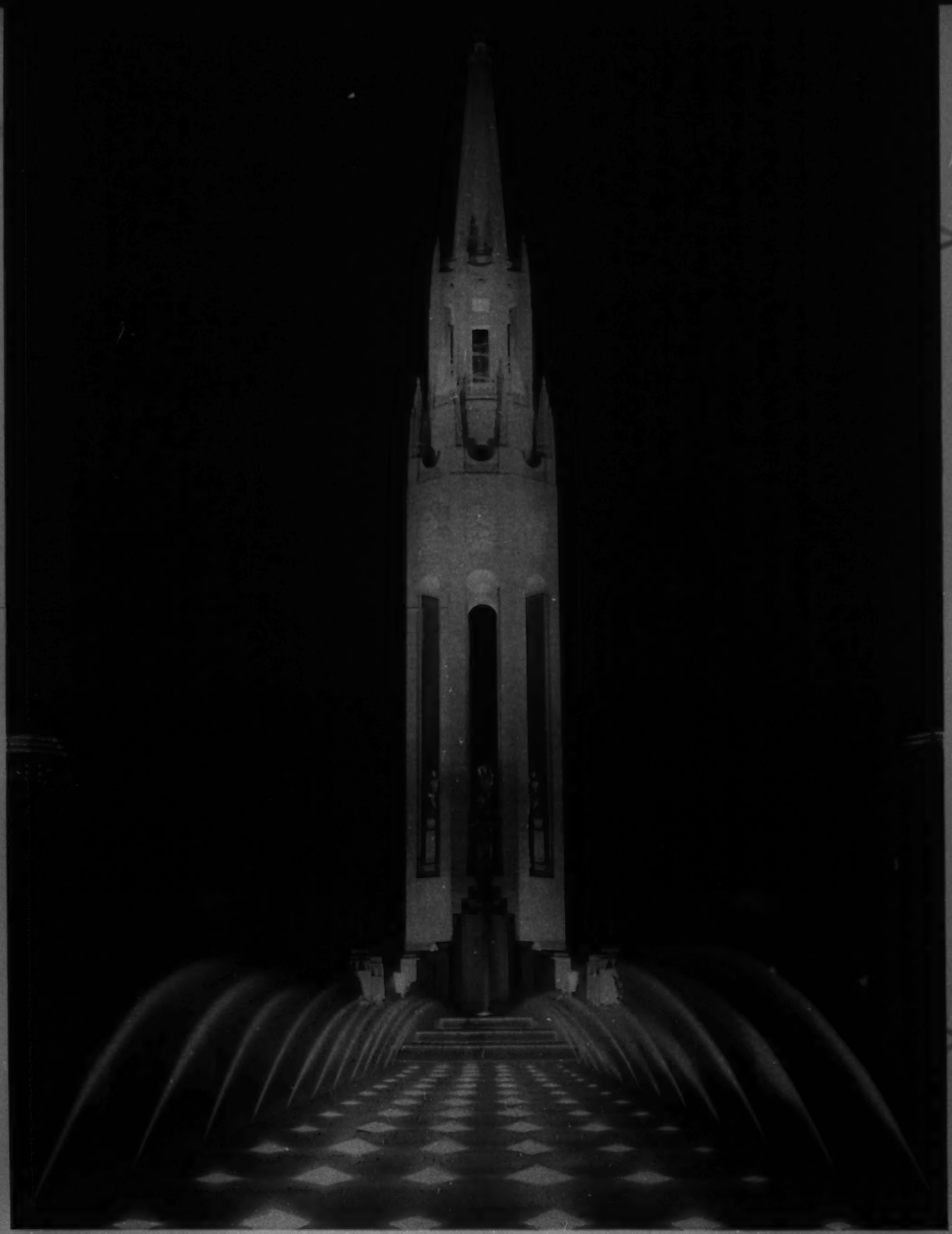


PLATE 11. Beginning with a warm amber at the base, the Tower of the Sun changes gradually to a white of increasing intensity at the top. Relief lighting is blue at the base, straw yellow at the belfry, amber at the pinnacle (Figs. 18, 19 and 20). The surrounding Court of Honor is mainly illuminated by this reflected light, although 24 decorative street lighting units supplement the design.

Elihu Thomson: Electrical Engineer

The "partially direct and partially indirect but ineradicable influence on electrical engineering" left by the first Edison Medalist is here surveyed by the 1938 recipient of that award.

DUGALD C. JACKSON
FELLOW AIEE

PEOPLE love to say that brilliant achievements belong to the early decades of maturity in men, and that brilliant attainments thereafter are foregone. However, whatever of truth there may be in the saying for men of moderate capacity, the latter part of it does not appear to be valid for men of unusual creative force. Elihu Thomson was one of the latter. His creative mind was forging achievements while he was in his early twenties and it continued in that manner of activity until near the illness which culminated in his death close to the end of his eighty-fourth year. Those were some sixty years of achievement. His major attention during that long period was on electrical engineering. He made an impress on that branch of engineering which has been matched by very few.

Doctor Karl T. Compton has called Thomson an American Faraday; and, indeed, the mental qualities of these two men had much in common, although their tastes were in contrast. Whatever it is which determines a man's tastes, it is not wholly the environment either of youth or of maturity. Some peculiar combination of genes must have final influence. Faraday had many opportunities to turn from the cloisters of independent research but found his fascination in those cloisters. Thomson had opportunity to reside in the cloisters, but his fascination lay in the applications of science to men's purposes. Both of these great men started in chemistry. Both turned to the field of electromagnetism. Faraday made great achievements therein, including the signal discovery of electromagnetic induction. Thomson was prolific in inventions embracing the field of electrical engineering, in the range from individual devices to the foundations of an important special industry. Each turned to other attractions in science as age came on him.

Those who are ardent supporters of the influence of environment on any man's life may speculate on the question of whether, had Thomson worked in the intellectual and physical surroundings of the first third of the 19th century and Faraday in those of the last quarter of that century, their roles might have been reversed. However, this question is outside of my sphere here. It is for us to here consider Thomson's achievements in electrical engineering as they occurred in the last third of the 19th century and the first third of the 20th.*

I have reflected a good deal regarding Thomson's life and I am convinced that he did the things that he did because he liked to do them. I believe that Thomson was as sensitive to, and enjoyed, appreciation as highly as any man. Nevertheless, he did his work, neither for praise, nor for honors, nor for wealth, but primarily because it was of intellectual fascination to him. That was an ideal attitude for commencing a great career of creative invention when Thomson came into electrical engineering, which then was a field mostly covered with thickets of the partly known and a jungle of the unknown. Ampere, Faraday, and Maxwell had made some clearings with major strokes of investigation. Many inventors had followed on, with the endeavor to apply the master discoveries to useful purposes; but the strokes of most of these inventors were feeble. Thomson and a few other giants came in with bold strokes. Thomson thereby established for himself a place as one of those giants in applied electricity who brought to us our modern achievements in the serviceable and comforting uses of electricity and electrical apparatus.

Born in Manchester, England, in 1853, he was still a child when he came to this country with his parents who

Address delivered at the Thomson memorial meeting of the American Philosophical Society, Philadelphia, Pa., February 16, 1939.

Past-president Dugald C. Jackson is professor emeritus of electrical engineering, Massachusetts Institute of Technology, Cambridge. Much has appeared in recent issues concerning his activities and achievements, including a biographical sketch in January (page 50), and an outline of his qualifications for the Edison Medal in February (pages 64–6).

* It is an interesting reflection that Edward Weston, another of the great inventors whose work is a component part of the foundations of electrical engineering, also had a background of chemistry, and Charles F. Brush started his business life as a chemical expert.

settled in Philadelphia. His schooling was in Philadelphia, and he graduated from the Central High School in 1870. Before the end of that year he was appointed assistant professor of chemistry and mechanics in the same school and six years later he was made professor. In the meantime he started upon that independent career of investigation and invention which is at the center of his fame. Edwin J. Houston, nearly nine years older than Thomson, in those days was professor of natural philosophy in the Central High School and also was active in the affairs of the Franklin Institute. His encouragement may have been helpful to Thomson. A number of Thomson's earlier patents relating to electric arc lighting were jointly ascribed to himself and Houston.

It was at the Central High School that Thomson was brought into contact with various experiments of others, and he carried on for himself many experiments in the laboratories of the school and of the Franklin Institute. During this period he made numerous observations that were later drafted into inventions of importance in the electrical-engineering field. One of his first inventions was the dynamo intended to furnish current for electric arc lamps, which was built under his supervision in a small machine shop on Buttonwood Street and the windings of which he made wholly himself. This machine operated all right and proved capable of serving nine arc lamps in series. The outfit was installed in a basement bakery where it had to be operated in an atmosphere of high temperature. Thomson himself acted as operating attendant during a good part of the early period of operation of this pioneer installation, and he enjoyed telling the story of how he protected himself from heat prostration by drinking, somewhat to the horror of his associates, large quantities of ice water. This "bakery machine," as Professor Thomson called it, is now among the exhibits at the National Museum in Washington.

At that time the Brush arc-light system was in commercial use, and other inventors in electrical engineering were struggling with the problem of suitable dynamos to provide arc-light current, but the problems imposed by the instability of the carbon arcs proved baffling to these inventors and none of them succeeded in those days in fully competing with the unique structure invented by Charles F. Brush and put out by the Brush Electric Company of Cleveland, Ohio. Thomson's uncanny sense of the relative fitness of things and his competency in putting together a well-adapted structure resulted in a dynamo which proved its capability for the purpose. Later, modified and fitted with a Thomson automatic brush-shifting regulator and an air-blast device for preventing destructive arcs at the commutator, Thomson's dynamo (shortly after 1880) became an important competitor in the arc-lighting field.

Series arc lighting has long ceased to be an important commercial factor, while other features of Professor Thomson's productive endeavors have steadily grown into wide influence and use in electrical engineering, but I am personally inclined to put forward this invention of the automatically regulated dynamo for arc-lighting service as a most important one for Thomson on account of its influence on his own later work and on the development of his opportunities.

The invention was made when he was still in his twenties; the construction and installation of the first machine were carried through substantially on his own responsibility except for meager financial aid; and there was drawn out from him at this early age an exhibition of those qualities of originality, courage, resourcefulness, far-sighted thinking, and power in experiment which were to prove to be so notably the foundation for his distinguished and productive career. It was the arc-lighting work, also, which led to the formation in 1880 of the American Electric Company with a small factory at New Britain, Conn., with the 27-year-old Professor Thomson as chief technical spirit; and which eventuated in the company's transfer three years later to Lynn, Mass., where its name became the Thomson-Houston Electric Company. At Lynn, Professor Thomson was established under the sympathetic and capable financial and executive management of Charles A. Coffin, and was happily provided with space and funds for a laboratory sufficient to his needs, in which to experiment, investigate, and invent.

He already had found need for automatic means for extinguishing the arc that results from the operation of old-style lightning arrestors attached to outdoor electric arc-lighting circuits and he demonstrated his grasp of principles relating to electric currents by inventing the "magnetic blowout." Thomson first applied it to lightning arrestors but later also applied it to many other types of devices, and now the magnetic blowout has become so commonplace an incident in electrical-engineering equipment that we often forget that Thomson found occasion to invent it from the whole cloth which was woven out of scientific principles.

In Thomson's early days, electrical engineering was a wilderness of the unknown or the little known for both engineering and science. It has grown to its present great structure of engineering interwoven with exact science as a consequence of the resourceful intellectual work of Elihu Thomson and his peers. Most of the designing and constructing of electrical machines and other apparatus in those early days was by rule-of-thumb and by keen application of intelligence to foresee the probable effects of modifications; in which latter Thomson held a mastery because of his acute powers of observation and his logical powers of mind. As his long-time assistant and colleague, Edwin W. Rice, Jr., said at Thomson's eightieth-birthday celebration, "Throughout his whole career Professor Thomson has exhibited an unerring capacity for the selection of that process which was soundest and best, and simplicity and directness always characterized his designs." And again, "He seems to possess an intuitive insight into nature, and her ways; probably because of the quickness and accuracy of his perception, combined with the depth and range of scientific knowledge, helped by a remarkably retentive memory."

Thomson's intellectual fertility and the scope of his ambition were not of common quality and did not rest satisfied with the arc-light situation, although it was his initiative and originality which had enabled his company

to take a foremost place in that art. Therefore we find him at Lynn soon making a mark in the development of other aspects of electric lighting, and of collateral branches in the electrical-engineering field. He found it irksome to lack reliable electrical measuring instruments and he designed his own instruments, with the result that he soon had reasonably accurate standards of resistance and reasonably accurate devices for measuring electric current, voltage, and power. In a short time, his company was manufacturing electrical measuring instruments to go along with its electric-lighting apparatus.

Incandescent lighting with the lamps in parallel on low-voltage circuits, with which we now are so familiar, was coming gradually into a place of importance, but there was no convenient and reliable form of integrating watt-meter to record the consumers' consumptions of watt-hours. Edison had produced a form of meter which recorded by electrolytic deposition, but that type was only serviceable in localities where a moderate chemical laboratory equipped with accurate weighing balances could be set up, and at the best was inconvenient and not very satisfactory. The problem was pressed on Professor Thomson's attention to the point of weariness until, by 1889, he had produced the typical standard integrating wattmeter that for so long has been known as the Thomson integrating wattmeter for direct currents, although it also is available for alternating currents. This was another pioneer milestone in the direction of the development of electrical engineering. Thomson's later inventions of integrating meters intended exclusively for alternating currents also came into importance. Along with the main conception of the first Thomson integrating meter went several lesser features, like the silver contacts at the commutator, which contributed to its perfection when in use.

That d-c integrating wattmeter was born when many people were crying for reliable customers' watt-hour meters and some were trying to produce a satisfactory embodiment. But until Thomson directed his mind to the problem, none had succeeded in visualizing the mechanical arrangement of parts or the electrical association of circuits that would give the desired result. Again Thomson's capable grasp of the principles of electromagnetism and of electric circuits as far as then known and his straightforward mental processes gave him the specific conception which produced the result when embodied as a physical device. As in the case of the magnetic-blowout device, it has seemed to me that a formulation of the scientific conception which steps aside from known arrangements, rather than an arrangement of parts, constituted the invention. Possessing the scientific conception, it was easy to form and interrelate the physical parts needed to produce an embodiment. This aspect of the process of inventing partakes of the qualities of scientific discovery in addition to the conventional qualities usually ascribed to invention, and it is of a much higher order than the character of invention which is satisfied with usefully modifying arrangements of parts. Thomson's life shone continuously with the light of this higher order of scientific discovery and invention.

The patent for Thomson's integrating wattmeter was declared invalid in England for lack of invention by a judge following the advice of an expert who testified that, possessing a "tip" which was already in the art, he would have known how to produce the meter. It has always seemed to me that the invalidating decision was an error. The expert, an electrical engineer, was a very experienced and capable experimenter, designer, and inventor, far above the level of a man "ordinarily skilled in the art" at the time of Thomson's distinguished conception, and granting that his statement before the court was correct, it is reasonable to believe that (thinking after the event) he underestimated the intellectual effort required for the conception, which lifted it far above the mental caliber of "one ordinarily skilled." This is an illustration of the embarrassment which we all experience when trying to understand past relations and the significance of former achievements, because we have difficulty in laying aside knowledge and prejudices gained from our present-day life. Similar difficulties beset and mislead many people when they essay to appraise achievements in other fields compared with those in the field of their own endeavor.

Electrically operated contact devices and all sorts of ancillary devices for the electrical-engineering field also came out of Thomson's laboratory in those days. But he was early in reaching correct concepts regarding the designing of dynamos and he already had become immersed in the problems of designing and manufacturing generators and motors for use in the commercial production and distribution of electric power. Mr. Edison, that great leader in the invention of electric lamps and electric-power distribution arrangements, held definitely to direct currents; but Thomson (along with others) came to the early realization that alternating currents could be made very serviceable, provided safe means of distributing the currents generated at high voltage could be visualized. Indeed, while still in Philadelphia, Thomson demonstrated the reversibility of the Ruhmkorff induction coil, which apparently satisfied him of the practicability of using transformers with a-c circuits, and an early patent was issued to him for an electrical distribution system using transformers in parallel on the circuits.

However, the safety to customers whose premises might through a fault be invaded by current directly from high-voltage a-c circuits, even when the voltage normally on any customer's premises had been reduced to a moderate figure by means of a transformer, gave Thomson much concern and thought. He became a foremost early proponent of the practice of metallically grounding the secondary or low-voltage circuits leading from a transformer, which is a practice that is still generally followed. He also invented a device for automatically protecting the circuits in case of failure in the insulation of the high-voltage winding of a transformer.

His mind continually ranged over the field of electrical applications and he constantly produced improvements. These seem often to have been the result of brilliant thoughts which led to arrangements so simple and at the same time so effective, when the thoughts had been applied in physical embodiments, that no one without prior knowledge thinks of the intellectual effort that was neces-

sary to be exercised in order to accomplish the ends. He introduced the reactor as a controlling device for a-c circuits. He perfected series arc-lighting practice for a-c circuits by inventing the automatic self-regulating transformer to convert alternating currents of constant voltage into alternating currents of constant amperes. He early proposed the use of oil filling for transformer cases, to provide dielectric support for the solid insulation in a manner which we still follow. He went into fruitful experiments with high-frequency electric currents; other experiments in the X-ray art when the knowledge of X rays was new and obscure; and experiments relating to electric resistance furnaces; all guided by that intellectual perception of scientific interrelations, and of measures of logical reasoning, on which I have previously commented. Professor Thomson's own notable résumé of his long life of experiment, discovery, and invention is to be found in the 50th Anniversary number of ELECTRICAL ENGINEERING, published by the AIEE, May 1934. I will not continue with a general enumeration but will turn to just two more of his contributions of physical nature.

In connection with alternating currents he pursued a fascinating thread of pioneering experiments with the repulsions produced by certain arrangements of a-c circuits. His paper presented to the AIEE in May 1887, entitled "Novel Phenomena of Alternating Currents," brought world attention to these features of a-c circuits. The phenomena to which he thus called attention, and some applications which he himself made, are now used in innumerable electrical-engineering devices. The path of development is too wide for me to trace here, but this is another instance in which Professor Thomson left a partially direct and partially indirect but ineradicable influence on electrical engineering.

In electric welding by the resistance process, he made the original discovery in Philadelphia in 1877, and this led to a series of inventions beginning in 1886 which, together with the De Meritens arc-welding inventions owned for this country by his company, have been the foundations of a notably useful special industry of widespread application.* (The first electric welding transformer, built in 1886, is pictured with the inventor on page 251.)

Elihu Thomson with his former pupil and associate, E. W. Rice, Jr., who at the time of his death was honorary chairman of the board, General Electric Company

Thomson possessed from his early days a sense of the desirability of standardization where standardization is desirable, and also of the desirability of improvement and the introduction of essentially new objectives where change is desirable. His intellectual balance held eminently good between these two tendencies. When the International Electrical Congress and its International Chamber of Delegates were convened in St. Louis in 1904, Professor Thomson was the president. Out of this meeting there arose the International Electrotechnical Commission with Lord Kelvin its first president and Professor Mascart its second president. Professor Thomson was its third president, holding a term from 1908 to 1911. He thereafter always maintained an active interest in the affairs of this organization and exerted a steadying influence on the complex affairs of international standardization in the field of applied electricity.

I cannot leave my topic without tracing briefly Thomson's effect on electrical engineering through the young men who came under his influence directly, and through his own relations with formal electrical-engineering education. His title of professor came from the Central High School of this city of Philadelphia. One of the first young men whom he had associated with him in business was E. W. Rice, Jr., who was first a loyally admiring student of Thomson and then, becoming his assistant in New Britain, participated jointly with Thomson in some of his inventions. Rice, who rose to very high place in electrical engineering, was throughout his life always insistent on his obligation to Thomson and on his wealth of fortune from having been closely associated with his professor.

I have known many others who came into association with Professor Thomson as assistants in the Company's early laboratory at Lynn. Most of them, like Professor Thomson and his old student and colleague Rice, have gone to their great reward and cannot give us their own testimony, but I can say for them how extraordinary was the unanimity of their sense of the intellectual welfare that they derived from their relations with Thomson. Many of these men became contributors of importance in the progress of electrical engineering.

As the affairs of the company became more widespread, Thomson was no longer so intimate with the personnel, but among the younger men who came into intimacy with him and are active contributors in electrical engineering, there appear the same expressions of gratitude for their contacts with Thomson as an advisor and mentor.

* In recent testimony before the Temporary National Economic Commission, Hon. Conway P. Coe, U.S. Commissioner of Patents, included the fundamental Thomson welding patent among 16 fundamental patents which he selected to illustrate the great influence of patented inventions on the origination and development of important new industries.

Professor Thomson throughout his life continued his interest in the formal processes of education. During more than 40 years he was an active figure in the affairs of the Massachusetts Institute of Technology. He was a non-resident member of the electrical-engineering staff from 1894 to the time of his death, and from time to time lectured on some special topic in electrical engineering, besides frequently holding membership in or the chairmanship of the MIT visiting committee for the electrical-engineering department, and holding membership in the joint committee from MIT and the General Electric Company which was responsible for establishing the co-operative course in electrical engineering at MIT. He was a busy man, but he took a lively interest in these electrical-engineering activities at MIT, which were in addition to his close relations to the institution as a member of its corporation and for a period its acting president. He also cheerfully gave of his time and thought as a visitor or advisor to other educational institutions.

I have not attempted to enumerate in full the achievements of Professor Thomson in electrical engineering and I have spoken little of the honors which came to him in that field; nor have I referred to his lively interest in other scientific fields. Rather have I endeavored to convey to you in a broad way the impress which his works have made in electrical engineering and to give an appreciation of the intellectual quality which underlay all of his important engineering affairs. If I have succeeded in this attempt you will have realization of why the electrical engineers of this country gladly conferred on Professor Thomson the highest honors that are within their powers collectively to bestow: President of the AIEE, Honorary Member thereof, the first conferred Edison Medal, the jointly awarded John Fritz Medal; besides yielding to him their affectionate and friendly admiration. American electrical engineering thus has crowned Thomson formally with its best laurels in recognition of his great and permanent contributions to the advancement of its art. A like attitude of recognition for his works stands out among the electrical engineers of nations abroad.

Room Noise at Telephone Locations

D. F. SEACORD
ASSOCIATE AIEE

Measurement of noise levels in a wide variety of locations provides data that are valuable in the design of telephone plant

SINCE the degree of satisfaction with which speech is received over a telephone connection depends on the room noise at the point of reception as well as on the physical elements comprising the telephone circuit, a knowledge of room-noise conditions at telephone locations is of considerable interest to the telephone engineer. As a consequence, measurements of room noise have been made from time to time by the Bell System. The earliest measurements, which were made at relatively few locations, were based on subjective methods.

In 1929, a survey of room noise was carried out by the National Electric Light Association and the American Telephone and Telegraph Company in the course of the work of their Joint Subcommittee on Development and Research. While this survey, covering some 250 locations, was considerably broader than any previously made, it was confined largely to the territory in and around New York City. An early type of objective meter was used in addition to subjective methods. Further objective measurements, using measuring equipment meeting the present specifications of the American Standards Association for sound-level meters, were made during 1936 and 1937 at over 600 locations in four cities, in connection with field tests of the new telephone sets.

Late in 1937, the Bell Telephone Laboratories, in conjunction with several of the associated telephone companies, commenced a still broader survey of room noise. This survey has covered a wide range of different types of locations in various types of areas ranging from rural to congested city districts in and around various major cities. Measurements were made under winter conditions at about 900 locations in and around Chicago and Philadelphia; these data were supplemented by summer measurements at about 500 of these locations. In addition, further data were obtained under summer conditions at about 800 locations in the territory in and around Cleveland and New York, including, in the latter area, nearby locations in New Jersey.

Report presented at the conference on sound, AIEE winter convention, New York, N. Y., January 23, 1939.

D. F. Seacord is an engineer for the Bell Telephone Laboratories, New York, N. Y.

Although analysis of the measurements made at the total of some 2,200 locations during the latest survey has not yet been completed, some of the results of the preliminary analysis may be of interest, particularly with regard to the average and range of room-noise values measured at various types of locations. The results of the measurements made during the winter in the Chicago and Philadelphia areas, which have been analyzed in considerable detail, are used as the basis of this article. With regard to the difference between summer and winter room noise, comparisons between the measurements made at identical locations under summer and winter conditions in the Chicago and Philadelphia areas indicated, on the average, an increase in room noise of the order of two to three decibels for the summer condition, although there is, of course, considerable range in the differences obtained at individual locations.

The measuring equipment, including a 40-decibel loudness-weighting network, conformed to the specifications described in the ASA "Tentative Standards for Sound Level Meters" (Z 24.3–1936). The microphones used were of the moving-coil type, and the meters used read sound level in decibels above reference sound level, that is, 10^{-16} watt per square centimeter at 1,000 cycles in a free progressive wave.

In both the Pennsylvania and Illinois surveys, typical areas were selected covering the range from congested city districts to rural districts. In any particular area the judgment of the engineer on the job was relied upon to obtain representative locations, which ranged from factories and large stores and offices to small detached residences. At each location 50 instantaneous readings, 25 by each member of a two-man crew, were made of the noise as indicated by the sound-level meter at approximately five-second intervals. The average of the 50 readings is taken as the average noise and the concentration of the individual values near the average (that is, the standard deviation) is computed as a measure of the variability of the data. It is obviously impractical to obtain sufficient data for each type of location in each area to define rigorously the room noise at such locations; sufficient data were obtained, however, so that by combining similar types of locations in the various areas, noise values considered sufficiently accurate for engineering purposes were secured.

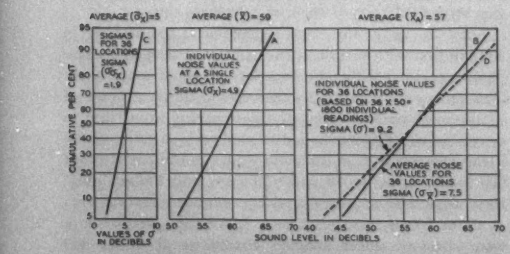

AVERAGE ($\bar{\sigma}_x$)=5
AVERAGE ($\bar{X}$)=59
AVERAGE ($\bar{X}_A$)=57
SIGMAS FOR 36 LOCATIONS
SIGMA (σ_{σ_x}) =1.9
INDIVIDUAL NOISE VALUES AT A SINGLE LOCATION SIGMA (σ_x)=4.9
INDIVIDUAL NOISE VALUES FOR 36 LOCATIONS (BASED ON 36 X 50= 1800 INDIVIDUAL READINGS) SIGMA (σ')= 9.2
AVERAGE NOISE VALUES FOR 36 LOCATIONS SIGMA ($\sigma_{\bar{x}}$)= 7.5
CUMULATIVE PER CENT
VALUES OF σ IN DECIBELS
SOUND LEVEL IN DECIBELS

Figure 1. Distributions of room noise, based on combined data obtained at 36 medium-sized offices (Pennsylvania and Illinois winter surveys)

Since room noise is a highly variable quantity, it is necessary to express the results of room-noise measurements in such a way that both the average value and the degree of variation involved are described. This may be done graphically by means of distribution curves as illustrated in figure 1. The scale used in this figure, which is known as an arithmetic probability scale, is such that cumulative normal distribution curves appear as straight lines. The

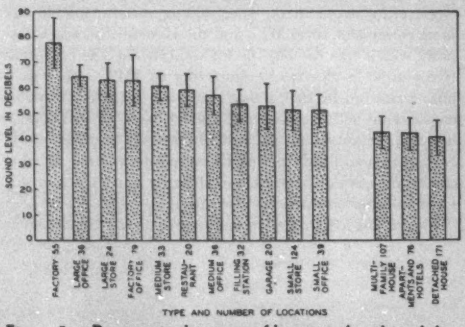


Figure 2. Room noise by types of locations (combined data from Pennsylvania and Illinois winter surveys)

data used for this illustration are based on measurements of room noise at 36 medium-sized offices (from three to ten desks). Curve *A* in figure 1 represents the distribution of the 50 individual readings taken at a single typical location; for a normal distribution the average value corresponds to the 50-per-cent point of the vertical scale. Similar average values were obtained for each of the 36 locations of this type, and the distribution of these average values is given by curve *B*.

Curves of the types shown on figure 1 may be expressed numerically in terms of the average value and a value known as the standard deviation, the latter term being a measure of the spread of a distribution such that approximately 68 per cent of the items have values within the range of plus and minus one standard deviation from the average value. Figure 1 shows that since the character of the noise varies considerably from one location to another, the standard deviations will accordingly vary and cover the range from locations where the noise is fairly constant (low value for the standard deviation) to locations where the noise is highly variable (high value for the standard deviation). The distribution of the standard deviations for the 36 locations is shown as curve *C*. Curve *D* represents the distribution of the 1,800 individual readings (50 at each of 36 locations) and includes, in addition to the variation between the 36 average values indicated by curve *B*. the variation in the readings at each location The relation between the standard deviation of the over-all distribution (curve *D*) and the separate standard deviations indicated on figure 1 is given by the formula

$$\sigma = \sqrt{(\bar{\sigma}_x)^2 + (\bar{\sigma}_{\bar{x}})^2 + (\sigma_{\sigma_x})^2}$$

With the average values and standard deviations of

individual readings available for each location, the data have been combined, using the methods illustrated by the preceding discussion, to include results at a given type of location for all the areas measured in both the Pennsylvania and Illinois surveys. The results of such a combination of data are shown in figure 2, which covers 852 locations, of 14 types (11 business and 3 residence) for which data were obtained at a minimum of 20 locations per type.

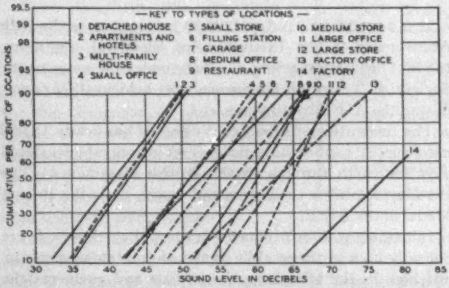


Figure 3. Distributions of room noise at 14 types of locations (combined data from Pennsylvania and Illinois winter surveys)

The height of the bars shown in this figure represents the average value of room noise for the number of locations indicated in the bar, and the single line extension above and below the top of the bar represents the range covered by plus and minus one standard deviation. The numbers shown represent the number of locations of each type measured and are not to be taken as representative of the relative distribution of such types of locations in the plant, as in some cases, such as factories and factory offices, for example, a relatively large number of locations were measured because of the wide variation in conditions.

The data shown in figure 2 are also shown in the form of cumulative distribution curves on figure 3. In this case arithmetic probability paper is used, on which straight lines represent cumulative normal distribution curves. The lines shown represent the normal curves which fit the data as obtained from the computed averages and standard deviations, and are distributions of the type indicated by curve *B* on figure 1. It is obvious that the data may be segregated into three reasonably distinct groups covering residence locations, business locations (including factory offices but excluding factories), and factories.

Distribution curves of the data combined on this basis are shown on figure 4. The data used for these curves are slightly different from those included in figures 2 and 3 in that they include seven types of business locations (a total of 48 locations) having less than 20 locations per type, and for residence locations exclude data taken where radios were in operation. Exclusion of the few instances of the latter reduced the average room noise at residence locations by about one decibel. In figure 4 the data for each of the three classes (residence, business, and factory) are plotted separately for the results of the Pennsylvania and Illinois surveys in five-decibel steps. In each case the points shown indicate the cumulative percentage of locations having measured average noise values less than the values given; the straight lines are normal distributions which the actual distributions approximate. These curves, incidentally, closely check the normal distribution curves which would be obtained from the computed averages and standard deviations of the data. For residence and also for business data, a single curve represents closely the distributions obtained from both Pennsylvania and Illinois. The Pennsylvania factory-noise data, however, is materially higher than the corresponding Illinois data, possibly because of different types of manufacturing establishments in the random selection of locations in the two states.

In summarizing the results of the survey of room noise at telephone locations, it is desirable to emphasize again the variable nature of room noise. For example, the average noise values typical of different types of locations vary from about 40 decibels at residential locations to about 80 decibels at factories. Moreover, for a particular type of location the noise is by no means constant from one location to another; five per cent of the residences had average noise levels about 50 decibels, while another five per cent were lower than about 30 decibels, indicating a total range of over 20 decibels. The noise at some residences approaches in magnitude the average noise at business locations and the noise at some business locations approaches in magnitude the average noise in factories. The noise data obtained in these surveys are being used as a basis for devising methods that will reflect more accurately the effects of room noise in the design of telephone plant.

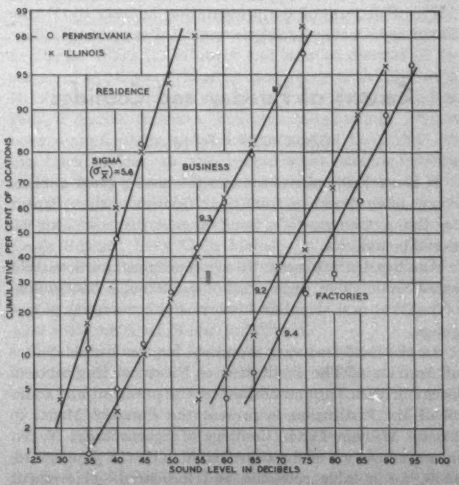


Figure 4. Comparison of the results of Pennsylvania and Illinois winter surveys on distribution of room noise in residence, business, and factory locations

"For Notable Scientific and Industrial Achievement in Electrical Engineering"

1938 Faraday Medal of The Institution of Electrical Engineers, Great Britain, presented to W. D. Coolidge at AIEE North Eastern District meeting

THE FARADAY MEDAL, awarded for 1938 to W. D. Coolidge (A'10, M'24), was presented at the AIEE North Eastern District meeting, Springfield, Mass., May 4, 1939, by Gano Dunn (A'91, F'12) honorary secretary for the United States of The Institution of Electrical Engineers of Great Britain. The award was conferred by the council of the IEE at its meeting on January 16, 1939.

Highest honor of the IEE, the Faraday Medal was established in 1921 to commemorate the 50th anniversary of the society's first ordinary meeting. It is awarded not oftener than once a year for notable scientific or industrial achievement in electrical engineering or conspicuous service rendered to the advancement of electrical science, without restriction as to nationality, country of residence, or membership in the society. Seventeenth recipient of the award, Doctor Coolidge is the third American to receive it, the others being AIEE Past-Presidents Elihu Thomson and F. B. Jewett. Nine of the 17 recipients have been members of the AIEE.

W. D. Coolidge is director of the research laboratories of the General Electric Company, Schenectady, N. Y., and one of the world's foremost X-ray scientists. A biographical sketch of him appeared in the March issue (page 137). Full texts of the presentation address by Doctor Dunn and Doctor Coolidge's speech of acceptance follow.

Careers of Faraday and Coolidge

GANO DUNN, Fellow AIEE

It is unusual, and it increases the honor, when a medal comes to an American from the other side of the Atlantic, for that is evidence of a fame broader than our own national boundaries.

And to a British honor, there is a peculiar character that enhances its value, on account of our common background of political and scientific history, and community of language.

As the local honorary secretary for the United States of America of The Institution of Electrical Engineers of Great Britain, I am authorized by the president and council of the Institution to present the Faraday Medal to Doctor William David Coolidge of Schenectady, N. Y., in consummation of the award made to him on January 16, 1939, for notable scientific and industrial achievement in electrical engineering.

The Faraday Medal has previously been given to only two Americans, Elihu Thomson and Frank B. Jewett.

It is a medal founded in 1921 to commemorate the 50th Anniversary of The Institution of Electrical Engineers, the first ordinary meeting of which, under the name of the Society of Telegraph Engineers, was held in 1871, antedating the AIEE by 13 years.

The Institution of Electrical Engineers has nearly 18,000 members, a considerable number of whom are scattered over the earth throughout the British Dominions. The Faraday Medal is their principal honor, as is the Edison Medal in the AIEE.

In naming it after Michael Faraday, they chose a figure not only high in the world's record of great achievements, but high in the affections of scientists and engineers the world over; on this account the award is without restrictions as regards nationality, country of residence, or membership in the Institution.

Fascination of Faraday's Life

To every scientist and engineer, there is a fascination in the career of the blacksmith's son apprenticed to a bookbinder, who devoted every moment of his precious leisure to watching the demonstrations of Sir Humphrey Davy from the gallery of the Royal Institution of London, in which, after becoming Sir Humphrey's assistant and then lecturer, he became resident professor, and put the whole world in his debt by his marvelous discoveries.

Faraday is of the type of genius, geometrical rather than mathematical. He asked questions of Nature in the form of experimental presentations devised in the assumption of brilliant working hypotheses, with a flair and a genius for the suspicion of truth long before it became evident. His world was objective and his processes intuitive.

He was the first to infer and later to prove a connection between magnetism and light, and to draw attention to the medium as the seat of phenomena, and he was the first to infer and later to demonstrate not only electromagnetic induction but the possibility of generating electricity from mechanical motion, a discovery on which depends not only the whole power and light industry of today, but so many others that if the discovery were removed, civilization would stop.

A deeply religious man, he left in his character a record as laudable as in his work. I cite these meager facts about Faraday to indicate why The Institution of Electrical Engineers selected him as the exemplar for their principal honor, and why that honor is the highest in their gift to give.

There is for Americans an association with Faraday of

which they are proud. It gives to the advent of a Faraday Medal in the United States a measure of sentiment, for it is in part to a distinguished American scientist and administrator that the Royal Institution, which gave Faraday his opportunity and his platform, owes its existence.

That American was Benjamin Thompson of Rumford Falls, N. H. A member of the Royal Society, he was one of the promoters of the Royal Institution. When ennobled by the Emperor of Austria, he chose the title Count Rumford, under which his experimental determination of the mechanical equivalent of heat and much other valuable scientific work is known.

The Roster of Faraday Medalists

1922	Oliver Heaviside*
1923	Sir Charles A. Parsons
1924	S. Z. de Ferranti*
1925	Sir J. J. Thomson
1926	Colonel R. E. B. Crompton
1927	Elihu Thomson*
1928	Sir J. A. Fleming
1929	Guido Semenza*
1930	Lord Rutherford
1931	C. H. Merz*
1932	Sir Oliver Lodge
1933	Sir Frank E. Smith
1934	F. B. Jewett*
1935	Sir William Henry Bragg
1936	André Blondel*
1937	Sir John Snell*
1938	W. D. Coolidge*

* AIEE member

Benjamin Thompson's part in the founding of the Royal Institution has always been associated in my mind with a reciprocal remarkable gesture of large generosity by a distinguished British scientist, James Smithson, who willed his whole fortune, which was delivered over here in gold coin, to the President of the United States, and certain other officers of the United States Government, eternally to found the great Smithsonian Institution in Washington.

If we are told about the essayist on the life of the Duke of Wellington who gave three-quarters of his space to the great military genius of Napoleon, we must bear in mind that he did it in order the better to display the Duke of Wellington as the world's greatest victor's victor. This is my motive in describing at this length the prestige and honor that lie behind the Faraday Medal.

Medalist Coolidge's Achievements

It has been awarded to our William David Coolidge of the AIEE (and of so many other scientific and engineering organizations that it is difficult to enumerate them) because of the trail he blazed in the virgin territory of the Roentgen rays (by which name the British still designate what we call X rays) and because of his later great work in that and other fields.

Doctor Coolidge experimented with tungsten for incandescent-lamp filaments and devised the amalgam process for making such filaments.

As far back as 1912 and 1913, he used the results of investigations of Doctor Langmuir in electron emission from hot filaments and produced the Coolidge X-ray tube, which gave complete control of the intensity and penetrating power of the rays, continuous operation without change in intensity, and complete absence of fluorescence of the glass. This tube accommodated voltages up to 200,000 volts, with a corresponding intensity of the rays, and a capacity for revealing new knowledge in widely scattered fields, in which these high voltages were employed for research.

In 1917 Doctor Coolidge brought out a complete portable X-ray generating outfit for military service in the field. This included a specially developed radiator-type tube of large heat capacity which was destined to supplant the earlier type of hot-cathode tube for all diagnostic work.

In 1924 Doctor Coolidge finished developing his oil-immersed self-contained X-ray outfits, which could be safely manipulated without expert technique, and which had many applications in dentistry, in physical laboratories generally, and in industry.

In 1928 Doctor Coolidge determined and explained the cold-cathode effect which limits the voltage that can be used on a given tube. For high voltages he developed a subdivided tube with intermediate tubular electrodes which accelerate the electrons at each stage, so giving an extremely high electron speed for bombardment of the final electrode. He predicted the use of this type of tube working on 2,000,000 volts, which would produce X rays as penetrating as the shortest wave-length gamma rays from radium.

In 1932 Doctor Coolidge presented a remarkable paper at the International Electrical Congress of Paris which put forward the results of his experiments on the "Behavior of Cathode Rays Outside the Generating Tube."

Recognition Awarded Coolidge

But these are not all his accomplishments. As assistant to Doctor Willis R. Whitney and later as director of research of the General Electric laboratory at Schenectady, N. Y., Doctor Coolidge's work in many fields, including that of ductile tungsten, has been outstanding. It has been recognized by the Edison Medal of the AIEE for his contributions to the incandescent electric-lighting and the X-ray arts, and by numerous other medals; in 1914 the Rumford Medal; in 1926 the Howard N. Potts Medal of the Franklin Institute of Pennsylvania and the Louis Edward Levy Gold Medal; in 1927 the Hughes Medal of the Royal Society of London, and the gold medal of the American College of Radiology; in 1932 the Washington Award of the Western Society of Engineers, and in 1937 the John Scott Medal and Award.

In addition to memberships in numerous scientific societies, he is an honorary member of the Roentgen Ray Society, the American Radium Society, the Radiological Society of North America, the American College of Radiology, the Roentgen Society (of England), the Société de Radiologie Médicale (of France), Nordisk Forening for Medicinisk Radiologi (of Scandanavia); and in 1927 he was awarded honorary degrees of doctor of science by Union College and by Lehigh University.

The Faraday Medal is like the laurel wreath of the

Greeks. It is of bronze rather than of gold, because it was particularly desired that there should be no suggestion of intrinsic value in the medal itself, but that it rather should owe its value, first, to the fact that it was instituted to commemorate the foundation of The Institution of Electrical Engineers, and, second, that it is offered for world-wide service to electrical science and electrical engineering.

In bestowing upon Doctor Coolidge the Faraday Medal, The Institution of Electrical Engineers is placing his name in a roster made illustrious by world-known names, to which roll of honor his name is a worthy addition.

Modern Developments From Faraday's Work

W. D. COOLIDGE, Member AIEE

I was sorry not to be able to go to England to receive this great honor directly from The Institution of Electrical Engineers. In some ways, however, it is not unfitting that I receive it through the kindly auspices of the AIEE, of which I have long been a member. Nor is it unfitting that I receive it in Springfield, Mass., for there are many factors connecting this locality with the event.

Benjamin Thompson was born in Woburn, Mass., only 86 miles from here, and he it was who, in 1796, formulated a plan which later resulted in the establishment of the Royal Institution in which Michael Faraday found the opportunity for his work.

Only a hundred miles west of here, in Albany, N. Y., another pioneer, Joseph Henry, carried out his early experiments in electromagnetic induction.

Professor Elihu Thomson, an earlier Faraday Medalist, spent many of the most productive years of his life in Lynn, Mass., only a hundred miles east of here. He was one of the most prolific of the pioneers in applying to the generation, utilization, and measurement of the electric current the principles of electromagnetic induction established by Faraday. Furthermore, I am sure it was Professor Thomson's influence, more than that of any other, upon his one-time pupil, later assistant, and, still later, chief, Doctor E. W. Rice, which was responsible for the foundation and active support of our Research Laboratory.

Finally, as one more factor connecting this locality with this event, my own birthplace is only a little over fifty miles from here.

But, if the location suggests geographical relations, the occasion emphasizes their unimportance. This award by a British institution to an American is one more bit of evidence of the fact that science knows no national boundary lines.

Tribute to Laboratory Associates

It is in a spirit of deep humility, so far as my own contribution is concerned, that I accept the honor conferred upon me by The Institution of Electrical Engineers in giving me this medal and adding my name to the illustrious group of Faraday Medalists who have preceded me. I must accept it not as a personal tribute but rather as a tribute to a splendid group of workers of which, for 33 years, I have been so fortunate as to be a member.

That group was organized by Doctor Willis R. Whitney. By precept and example, he succeeded in bringing about such close co-operation that it is difficult, if not impossible, for me or any other member of that group to point to any development brought to anything like full fruition, which he could call exclusively his own. I take this opportunity to acknowledge the inspiration and generous help which I have received from Doctor Whitney and from my associates.

The Electrical Industry's Debt to Faraday

And also I feel that I truly owe an acknowledgment to Michael Faraday, for his fundamental researches were an effective stimulus to the conception of our laboratory. Not only can the origin of many General Electric products be traced directly to his work—such as our generators and transformers, which are the engineering derivatives of his classic discovery of electromagnetic induction—but, since economic generation and distribution of electric power have made possible the development of our great electrical industry, it may truly be said that our company owes its existence, as part of that industry, to Faraday's experiments.

It was the clear recognition of that fact by Doctor E. W. Rice and his associates that led to the foundation of our laboratory, in the hope, as Doctor Rice expressed it, that it might result in the establishment of new facts and principles which could serve as the basis for new things to be made in our factories.

As one studies Faraday's work, one is impressed, first, by the magnitude and diversity of the contributions he made to science, and second, by the simple equipment with which he achieved such epoch-making results. When Helmholtz visited him

Faraday Medal being presented to Doctor Coolidge by IEE Honorary Secretary Dunn

toward the close of his life and inspected his laboratory, he wrote in astonishment about the few pieces of copper wire and iron bars which had sufficed for the most far-reaching discoveries.

I think that the director of any modern research laboratory would hate to compare the output of his laboratory per dollar spent for either equipment or salaries with that of Faraday's laboratory in the Royal Institution. He would need several excuses. In the first place he would point out that he had not been able to find many young Faradays for his staff, and in the second place that much of the fundamental research work of today calls for complex and expensive equipment.

Such is the inevitable result of progress in research. In pioneering in a new field, simple tools may suffice, but, with the fundamental principles discovered, further work demands highly specialized facilities, for refined measurement, tests under extreme conditions, and development of special applications.

Michael Faraday

Photograph reproduced from *The Telegraphic Journal and Electrical Review*, London, July 15, 1877

Extensions of Faraday's Research

This might be illustrated by many examples, taken from our recent work, of extensions of research along trails first opened by Faraday.

He recognized the need, in electromagnetic apparatus, of copper, insulation, and iron. With reference to the first of these, we have found it necessary to do much metallurgical research on copper. We have learned that we must free it of any oxide along grain boundaries if it is ever to be heated in a reducing atmosphere. Or, if it is to be stressed at elevated temperature, we may have to add silver to raise its equicohesive temperature and so prevent brittle fracture.

For primary insulation it has often been desirable first to enamel wire and then to wrap it with cotton or silk. Recent work has resulted in an enamel derived from polymerized vinyl acetate which is so adherent and so elastic that no other covering is needed, and so the space-factor is improved.

For secondary liquid insulation, non-inflammable pyranol has been developed, to be used in place of oil.

Recently we have become actively interested in the insulating properties of certain gases, notably the chlorine and fluorine derivatives of the methane hydrocarbon series. In the case of a new million-volt transformer-type X-ray outfit, 100 pounds of one of these compressed gases is furnishing insulation equivalent to that of 12,000 pounds of the liquid oil ordinarily used in transformers.

Research on transformer steel has been carried on continuously ever since our laboratory was started, and, as a result, magnetic losses have been reduced to less than one-fourth of what they were. Recent work has shown that, through the best amount of cold rolling, long narrow strips of steel may be produced having maximum permeability in the direction of their length, and that these, when preformed and annealed, can be wound around the primary and secondary coils to form the core of a transformer which for the same electrical performance is better mechanically, calls for less hand labor, and is some 40 per cent lighter in weight than its predecessors.

Faraday made many ferrous alloys and studied their physical properties. As ferrous alloys stronger at high temperature would make possible the attainment of higher economies in power production with both the steam and mercury processes, we are making many experimental alloy steels and testing them under sustained load at elevated temperatures. In this work special attention is paid to creep rate and to the determination of the equicohesive temperature range.

Some of our steel work has been in search of alloys having the same heat expansion as special glasses, to permit their being sealed together for the construction of vacuum tubes of various kinds and for other uses.

Much of our alloy work, both ferrous and non-ferrous, has been greatly facilitated by the pressed-powder method, with which we first became acquainted through the development of ductile tungsten and ductile molybdenum, and later carboloy.

Faraday studied the inactive or passive state of iron. We have recently been studying this in connection with the corrosion of stainless steel.

Faraday was interested in permanent magnets, both natural and artificial. We have been quite active in this field and, as a result, have seen the strength of permanent magnets gradually increased during the last 30 years some eight- or tenfold. The latest cast Alnico magnets consist of an alloy so hard that it cannot be machined. This would make the construction of small magnets of this material so expensive as to limit their use appreciably. We have recently found, however, that they can be made just as good, and for certain shapes much more cheaply, from pressed powder.

We are still actively interested in the sparks and arc-discharges with which Faraday worked. Only the dimensions have changed. Our latest 10,000,000-volt im-

pulse generator produces sparks 30 feet long, while another high-current impulse generator delivers a quarter of a million amperes—more current than has ever been measured in a lightning stroke.

Arc characteristics are being studied in various gases and at pressures up to more than a thousand atmospheres. At moderate pressures, arc discharges in neon and in mercury vapor are being studied as light sources, while the low-temperature mercury arc has been coupled with a phosphor to transform the ultraviolet radiation into visible light, and so to increase the light output.

In radio research and in television, we are continuing Faraday's work on electromagnetic action at a distance. The principles are those discovered by him and formularized by Maxwell, but the distances have outgrown both the laboratory and the earth.

Faraday's leadership is a never-failing inspiration. To follow in his footsteps is a privilege indeed. To have succeeded in pressing a little farther along the paths he pointed out brings a satisfaction which itself sufficiently rewards the effort.

European Welding Practice*

WELDING has grown to be as important a tool in engineering in Europe as it is in the United States. Welding machines in Europe are of high quality and in most countries of a-c equipment is far more widely used than d-c equipment. Special attention has been directed to low-rating machines for thin-gauge welding with the consequence that very excellent a-c and rectifier type sets have been developed for this work.

Welding electrodes in Europe are primarily of the shielded-arc type, although considerable quantities of bare and light-dipped electrodes are still in use in Germany and France.

Spot and other types of resistance welding are not in as common use as they are in America. There is great interest in this method, however, particularly for automobile, aircraft, and railway construction. Automobile manufacturers are considering installation of tube-controlled equipment for the production of duraluminum bodies. Gas welding, cutting, and brazing are in common use and very high-grade results are being obtained on all types of metals.

The industries in which welding is being used compare with those in the United States. Ships, buildings, bridges, railway coaches, autos, buses, elevators, pressure vessels, and all engineering equipment are now being fabricated by welding.

Although welding is now used in nearly every field of engineering, the indications both in Europe and America are that its development in the future will be even greater than in the past.

*Abstract of an address delivered by C. H. Jennings, engineer in charge of welding research, Westinghouse Electric and Manufacturing Company, at the annual convention of the Association of Iron and Steel Engineers, Cleveland, Ohio, September 27, 1938.

Lamp-Size Steam Generator

A STEAM generator no larger than an ordinary incandescent lamp has been developed by the lamp division of Westinghouse Electric and Manufacturing Company. Heating coils of the device are directly immersed in water, providing a thermal efficiency of 90 per cent. It can generate superheated steam from cold water in less than 15 seconds. The heater is made in 1,000-, 1,500-, and 2,000-watt sizes, with evaporating capacities up to 5.7 pounds of water per hour. Steam can be superheated by it to 350 degrees Fahrenheit.

The cylindrical case of the generator is $9^1/_4$ inches long, and is made of transparent chemical-resistant glass, capable of withstanding mechanical stress, internal pressure of 25 pounds per square inch, and instantaneous transfer from cold to boiling water or vice versa. The case is provided at one end with two heavy electrical terminals, welded or sealed directly into the glass, and another threaded pipe is sealed into the opposite end as a steam outlet. Resistance wire coiled on an insulating core occupies most of the interior, leaving space for only five ounces of water at a time.

The steam generated by the device can be used to sterilize dishes, glassware, instruments, utensils; or for pressure cookers, chemical laboratories, small-scale industrial operations. The generator can also be used to produce small supplies of distilled water for drinking, medicinal purposes, or garage use, and to provide hot water for ordinary domestic uses. It operates on an ordinary electric circuit. The accompanying illustration shows two of the small generators.

News

Of Institute and Related Activities

South West District Holds Successful Meeting

A VERY successful three-day meeting and Student Branch convention of the South West District was held in Houston, Tex., April 17–19, with headquarters in the Rice Hotel. Over 500 members, guests, and students attended and took part in the various activities arranged by the committees, such as technical sessions, inspection trips, and social functions. The subject of oil-field operations was treated by papers presented in three of the nine technical sessions. One of the high spots of the meeting was a talk on "Geophysical Prospecting," by L. W. Blau, of the Humble Oil and Refining Company, Houston. The meeting was opened at 10:00 a.m. Monday, April 17, by F. C. Bolton, vice-president, South West District AIEE. The address of welcome was given by H. O. Clarke, Jr., vice-president, Houston Lighting and Power Company.

Joint Luncheon With Houston Engineers Club

Tuesday noon a joint luncheon with the Houston Engineers Club was held in the ballroom of the Rice Hotel, at which John C. Parker, president, AIEE, was the principal speaker. Doctor Parker spoke of the broader aspects of the engineering profession and its relation to society.

Illustrating how modern civilization depends on the work of the engineer Doctor Parker referred to the alarm clock and the precision chronographic instruments, food cooking and preservation, the communication of intelligence, the radio, and talking motion pictures. On the other hand he spoke of the engineer as a product of civilization, citing that modern hydraulics owes much to the work of Leonardo da Vinci. Clerk Maxwell's work about three-quarters of a century ago provided a foundation for radio, and his experiments in flame work and combustion were vital to the petroleum industry. The opportunity that exists in the United States for the most advanced education at the lowest possible cost, is a result of the background of centuries of civilization. The dedication by the public of certain rights makes possible public utility enterprises, highways, bridges, and other works. Legislation gives engineers an opportunity to pursue their profession and earn a living, but resolutions and legislation cannot accomplish everything. He referred to the high code of ethics and traditional honesty of the engineering profession, and suggested that, if engineers would take back into their communities the factual methods of approach used in their work, they would contribute much of value to community life.

J. B. Dannenbaum, president of the Houston Engineers Club, presided at the luncheon. President Parker was introduced by District Vice-President Bolton.

Social Events and Entertainment

Over 300 attended the chief social event of the meeting, a dinner-dance held in the main ballroom of the Rice Hotel. A musical program of songs and dancing was presented by the Mary Jane Reynolds Dancing School.

On Monday evening a large number of members and guests attended a stag supper held at the Gulf Brewing Company, 5301 Polk Avenue.

Inspection Trips

Monday afternoon 332 members and students took part in three parallel inspection trips. First in popularity was a trip to the Deepwater Plant and the Champion Paper Company, both located on the ship channel, about 11 miles from meeting headquarters. The second was a trip to the Turning Basin and to radio stations KTRH and KPRC, which transmit simultaneously on the same antenna using different frequencies. This trip also included the San Jacinto Battleground and the new monument there. The third trip was an inspection of the local and toll offices of the Southwestern Bell Telephone Company and the underground networks of the Houston Lighting and Power Company. The trips were arranged by the transportation and inspection committee: L. K. Del'Homme, *chairman;* L. B. Bricker, J. M. Craddock, W. C. Geirisch, G. R. Swindell, and H. C. Taylor.

District Executive Committee Meeting

On Tuesday, April 18, a breakfast meeting of the District executive committee of the South West District was held in Banquet Room B of the Rice Hotel. The committee adopted a resolution to support the St. Louis Section in its request to hold the next meeting of the District in St. Louis. President Parker complimented the Houston Section for its work in connection with the District meeting and praised the District for its very active Sections and Branches. He reported the Institute to be in excellent condition financially, with growth more rapid than the rise of the general business index. Emphasizing the importance of keeping in contact with young engineers, President Parker suggested placing young men on Section and District committees, and recommending young men to headquarters for appointment on national committees. H. H. Henline, national secretary, discussed the growth of the Institute since 1902, when it had 1,550 members, to its present 67 Sections and 120 Student Branches, with nearly all members in the United States having Section affiliation. The last four Sections were created in areas formerly assigned to other Sections and plans are being developed for a new Section at El Paso, Texas. In regard to finances he said that some of the reserves were used in the depression period but they have been restored and there has been no reduction in essential Institute activities. He informed the committee that in some Sections subdivisions for specialized programs have been created to meet the needs of specialists.

Analysis of Registration at Houston Meeting

Classification	Location: Houston Section	District 7*	Other Districts	Totals
Members	84	107	19	210
Students	50	73		123
Men guests	95	47	9	151
Women guests	20	29	2	51
Totals	249	256	30	535

* Outside of Houston.

Other items of business considered were distribution of information on available speakers, time for installation of Section officers, sending program announcements to other Sections, and membership matters. The committee decided to hold its next meeting early in the autumn at Tulsa, Okla., the exact date to be decided later by the vice-president.

Student Activities

A large number of students and counselors attended a get-together luncheon given by the Houston Lighting and Power Company at Kelley's Restaurant Monday noon. President Parker addressed the gathering.

Wednesday noon the Rice Institute was host to a luncheon conference of Student Branch counselors and Branch chairmen.

During the meeting three student technical sessions were held, which were well attended. The following papers were presented:

Induction Motor Operation With Separately Excited Phase Advancer, D. L. Hall and B. D. Low, The Rice Institute.

Failure of Cement-Insert Porcelain Insulators, G. M. Lee, Graduate Student, University of Missouri.

Application of Tensor Analysis to Electrical

NETWORKS, R. P. Haviland, Missouri School of Mines and Metallurgy.

AN A-C NETWORK ANALYZER, T. E. Acord, University of Texas.

DIRECTIONAL ANTENNAS FOR BROADCAST STATIONS, R. B. Bonney, University of New Mexico.

FIBER GLASS AS AN ELECTRICAL INSULATION, Leslie Lawrence, Oklahoma Agricultural and Mechanical College.

THE INVESTIGATION OF PROPELLERS FOR WIND-ELECTRIC PLANTS, E. P. Smith, Kansas State College.

VARIATION OF INDUCTANCE WITH BAR CORE LENGTH, C. H. Thomas and J. C. Burt, Texas Technological College.

IMPEDANCE RELATIONS OF THREE-WIRE SECONDARY SINGLE PHASE TRANSFORMERS WITH UNBALANCED LOADINGS, R. W. Townsend, University of Oklahoma.

CENTRAL PLANT SYSTEM OF AIR CONDITIONING, Charles Dawson, Southern Methodist University.

ANALYSIS OF THE INDUCTANCE OF IRON CORE COILS, R. R. Jenner, University of Kansas.

TRANSFORMER HEAT RUN BY DIRECT CURRENT OPPOSITION METHOD, L. W. Gregory, The Agricultural and Mechanical College of Texas.

MAGNETIC RECORDING, E. G. Goddard, New Mexico State College of Agriculture and Mechanic Arts.

A METHOD OF LINE VOLTAGE CONTROL, A. N. Atsar, Graduate Student, University of Missouri.

STROBOSCOPIC MEASUREMENT OF SLIP BY BEAT FREQUENCY, Elmo Crump, University of Missouri.

At the conclusion of the presentations the judges awarded first place to the paper by C. H. Thomas and J. C. Burt; second place to the paper by R. B. Bonney; and third place to the paper by Elmo Crump.

Jackson Lectures Published. "Engineering's Part in the Development of Civilization," a series of six lectures by Dugald C. Jackson (A'87, F'12) has been published as a 114-page cloth-bound volume by The American Society of Mechanical Engineers. These lectures, which were first presented at the University of North Carolina, Raleigh, and printed in the July to December 1938 issues of *Mechanical Engineering*, trace the relation of technological development to human history and stress the responsibility of modern engineering to the future. An article by Dr. Jackson on a related theme "The Social Significance of Engineering," was published in ELECTRICAL ENGINEERING, February 1939, pages 59–63. Copies of the volume of lectures may be secured at $1.55 each from ASME headquarters, 29 West 39th Street, New York, N. Y.

Future AIEE Meetings

Summer and Pacific Coast Convention (combined)
San Francisco, Calif., June 26–30, 1939

Great Lakes District Meeting
Minneapolis, Minn., September 27–29, 1939

Middle Eastern District Meeting
Scranton, Pa., October 11–13, 1939

Winter Convention
New York, N.Y., January 22–26, 1940

Program Completed for Summer and Pacific Coast Convention

THE AIEE summer and Pacific Coast convention, which will be held in San Francisco, Calif., June 26–30, 1939, by virtue of its location offers members and guests unusual opportunities. As an added attraction the Golden Gate International Exposition on Treasure Island will be in full swing, not to mention the scenic opportunities afforded when traveling to San Francisco from north, east, or south.

Information on the various recreational and social features of the meeting and on scenic attractions for those traveling to and from the convention, together with a tentative schedule of events, appeared in the May issue, pages 217–18. The schedule of events is now complete, with one minor change, as follows: the informal dinner scheduled for 6:00 p.m., Tuesday, June 27, will be held at the Yerba Buena Club instead of in the California State Building. Details of the business and technical program are given in the accompanying tabulation.

Business and Technical Program

Advance copies of papers will be made available as approved. Cost: mail orders, 10 cents per copy; if purchased at headquarters or at the meeting, 5 cents per copy. Because preprints are furnished at less than cost, and to avoid bookkeeping expense, payment with order is requested. Coupon books in $1 and $5 denominations are available for those who wish to avoid remittance by check or otherwise.

Monday, June 26

8:30 a.m. Registration (also Sunday, June 25—2:00 to 8:30 p.m.)

10:00 a.m. Annual Meeting

Opening of session. S. J. Lisberger, chairman, summer and Pacific Coast convention committee

Address of welcome. P. M. Downing, past vice-president

Response. Harry W. Hitchcock, nominee for vice-president

Board of directors' report (in abstract) H. H. Henline, national secretary

National treasurer's report. W. I. Slichter

Committee of tellers' report on election of officers

Presentation of president's badge and response from President-Elect F. Malcom Farmer

Presentation of prizes for papers

Presentation of Lamme Medal to Marion A. Savage

President's address. Dr. John C. Parker

2:00 p.m. Conference of Officers, Delegates, and Members

Tuesday, June 27

9:00 a.m. Power Generation and Transmission

39–119. MINGLED HYDRO AND STEAM POWER PRODUCTION IN CALIFORNIA—PAST, PRESENT, AND FUTURE. A. H. Markwart, Pacific Gas and Electric Company

39–120. THE USE OF MULTI-WINDING TRANSFORMERS WITH SYNCHRONOUS CONDENSERS FOR SYSTEM VOLTAGE REGULATION. H. P. St. Clair, American Gas and Electric Service Corporation

39–121. WAVE SHAPE OF 30- AND 60-PHASE RECTIFIER GROUPS. O. K. Marti, Allis-Chalmers Manufacturing Company, and T. A. Taylor, Bell Telephone Laboratories, Inc.

39–122. LIGHTNING INVESTIGATION ON TRANSMISSION LINES, VII. W. W. Lewis and C. M. Foust, General Electric Company

9:00 a.m. Communication, Electronics, and Basic Sciences

39–146. RECENT DEVELOPMENTS IN TELEGRAPH SWITCHING. F. E. d'Humy and H. L. Browne, The Western Union Telegraph Company

39–116. IONIZATION TIME OF THYRATRONS. A. E. Harrison, California Institute of Technology

39–117. TRANSFORMATION THEORY OF GENERAL STATIC POLYPHASE NETWORKS. Louis A. Pipes, Harvard University

39–147. RADIO FREQUENCY HIGH-VOLTAGE PHENOMENA. A. A. Alford and Sidney Pickles, Mackay Radio and Telegraph Company

9:00 a.m. Instruments and Measurements and Automatic Stations

39–124. A HIGH GAIN D-C AMPLIFIER FOR BIOELECTRIC RECORDING. Harold Goldberg, University of Wisconsin

39–115. SURGE VOLTAGE BREAKDOWN CHARACTERISTICS FOR ELECTRICAL GAPS IN OIL. R. W. Sorensen, California Institute of Technology

39–114. THE ANOMALOUS BEHAVIOR OF THE MOVING SYSTEMS OF SINGLE-PHASE A-C WATT-HOUR METERS AT NO LOAD. F. C. Holtz, Sangamo Electric Company

39–125. SOME PRACTICAL MEASURING DEVICES. Lloyd F. Hunt, Southern California Edison Company

39–93. CARRIER CURRENT LOSSES MEASURED, AND INTERFERENCE MINIMIZED ON BOULDER-LOS ANGELES TRANSMISSION LINES. J. D. Laughlin, Bureau of Power and Light, City of Los Angeles, and W. E. Pakala and M. E. Reagan, Westinghouse Electric and Manufacturing Company

39–126. A NEW TIME STANDARD. Henry E. Warren, Warren Telechron Company

Business and Technical Program

Wednesday, June 28

9:00 a.m. **General Session**

Address by a nationally known speaker (To be arranged)

2:00 p.m. **Conference of Officers, Delegates, and Members**

2:00 p.m. **Student Technical Sessions**

7:00 p.m. **Student Branch Dinner, Followed by Joint Conference of Student Delegates and Counselors of Eighth and Ninth Districts**

Thursday, June 29

9:00 a.m. **Protective Devices**

39-132. High-Capacity Hydro-Blast Circuit Breaker for Central Station Service. **W. F. Skeats** and **W. R. Saylor**, General Electric Company

39-128. "Magne-Blast" Air Circuit Breaker for 5,000-Volt Service. **E. W. Boehne** and **L. J. Linde**, General Electric Company

39-130. Transient and Steady State Performance of Potential Devices. **E. L. Harder, P. O. Langguth,** and **C. A. Woods, Jr.**, Westinghouse Electric and Manufacturing Company

39-127. Twelve-Kv Metal Enclosed Bus and Switch Structure Station "C." Oakland Pacific Gas and Electric Company. **F. S. Benson**, Pacific Gas and Electric Company, and **H. E. Strang**, General Electric Company

39-129. Testing of Distribution Arresters. **Herman Halperin**, Commonwealth Edison Company

39-131. Sensitive Ground Protection for Radial Distribution Feeders. **Lloyd F. Hunt** and **J. H. Vivian**, Southern California Edison Company, Ltd.

9:00 a.m. **Communication: Joint Session With Institute of Radio Engineers**

IRE paper. The Klystron as a Generator of Very Short Waves. **W. W. Hansen, R. H. Varian, D. L. Webster,** and **J. R. Woodyard**, Stanford University

39-144. Instruments and Methods of Measuring Radio Noise. **C. V. Aggers**, Westinghouse Electric and Manufacturing Company, **Dudley E. Foster**, Radio Corporation of America and **C. S. Young**, Pennsylvania Power and Light Company

39-145. Methods of Controlling Radio Interference. **C. V. Aggers**, Westinghouse Electric and Manufacturing Company

IRE paper. The Technical Framework of Our Television. **E. W. Engstrom**, RCA Manufacturing Company

9:00 a.m. **Electrical Machinery**

39-105. The Hydrogen-Cooled Turbine Generator. **D. S. Snell**, General Electric Company

39-97. Hydrogen-Cooled Turbine Generators. **M. D. Ross** and **C. C. Sterrett**, Westinghouse Electric and Manufacturing Company

39-106. Some Factors in the Mechanical Design of High-Speed Turbo-Generators. **S. H. Mortensen**, Allis-Chalmers Manufacturing Company, and **J. J. Ryan**, University of Minnesota

39-107. Special Problems of Two-Pole Turbine Generators. **C. M. Laffoon** and **B. A. Rose**, Westinghouse Electric and Manufacturing Company

39-133. The Direct-Acting Generator Voltage Regulator. **W. K. Boice, S. B. Crary, G. Kron,** and **L. W. Thompson**, General Electric Company

39-134. Fractional-Slot and Dead-Coil Windings. **Michel G. Malti** and **Fritz Herzog**, Cornell University (Presentation by title)

39-135. Report of Progress of the Art in Electrical Machinery. Committee on electrical machinery

2:00 p.m. **Conference on Teaching of Communication and Electronics**

2:00 p.m. **Conference on Sensitive Ground Protection**

This conference is expected to include group discussions of rotating apparatus, high-voltage transmission lines, and distribution circuits, particularly from the relaying point of view. Included in the discussion may be material relating to the flow of current in the earth from grounded conductors as a phenomena

2:00 p.m. **Student Technical Sessions**

Friday, June 30

9:00 a.m. **Transportation and Lighting**

39-138. Signal System, Interlocking Plants, and Automatic Train Control on the San Francisco-Oakland Bay Bridge Railway. **C. R. Davis**, Public Works Department, State of California

39-139. Electrical Equipment of the Union Pacific Steam-Electric Locomotive. **M. R. Hanna** and **J. F. Tritle**, General Electric Company

39-137. New Type of D-C to A-C Vibrator Inverter. **O. Kiltie**, General Electric Company

39-136. Painting the Golden Gate International Exposition With Light. **A. F. Dickerson** and **H. E. Mahan**, General Electric Company

9:00 a.m. **Research and Cables**

39-111. The Dielectric Strength and the Life of Impregnated Paper—The Influence of the Density of the Paper. **J. B. Whitehead**, Johns Hopkins University

39-112. Dielectric Strength of Insulating Liquids in a Continuously Circulating System. **H. H. Race**, General Electric Company

39-113. Tests on Oil Impregnated Paper, IV—Mechanism of Breakdown. **H. H. Race**, General Electric Company

39-140. A New Technique for Lead Cable Sheathing. **B. B. Reinitz** and **R. J. Wiseman**, The Okonite-Callender Cable Company

9:00 a.m. **Industrial Power Applications**

39-141. Temperature Survey of the United States. **J. J. Smith**, General Electric Company, and **H. W. Tenney**, Westinghouse Electric and Manufacturing Company

39-118. Capacitor Relay Timing in Industrial Control. **Carroll Stansbury** and **T. B. Jochem**, Cutler-Hammer, Inc

39-143. Electrical Engineering and the Petroleum Refiner. **G. R. Weeks, H. W. Giesecke,** and **C. M. Lathrop**, Standard Oil Development Company

39-142. Variable Voltage Equipment for Rotary Drilling Rigs. **E. H. Lamberger**, Westinghouse Electric and Manufacturing Company

1939 Lamme Medal Nominations Due December 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the AIEE Lamme Medal, to be awarded early in 1940, may be submitted by any member in accordance with Section 1 of Article VI of the bylaws of the Lamme Medal committee, as quoted in the following:

The committee shall cause to be published in one or more issues of Electrical Engineering, or of its successors, each year, preferably including the June issue, a statement regarding the "Lamme Medal" and an invitation for any member to present to the national secretary of the Institute by December 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least three engineers of standing who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee to enable the committee to determine its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specific information should be given regarding his individual contributions. Names of endorsers should be given as specified in the foregoing quotation.

The Lamme Medal, founded as a result of a bequest of the late Benjamin Garver Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company (deceased July 8, 1924), provides for the annual award by the Institute of a gold medal —together with bronze replica thereof— to a member of the AIEE "who has shown meritorious achievement in the development of electrical apparatus or machinery"; and for the award of two medals in some years if the accumulation of funds warrants.

The eleventh (1938) Lamme Medal has been awarded to Marion A. Savage (A'21) designing engineer, General Electric Company, Schenectady, N. Y., "for able and original work in the development and improvement of mechanical construction and the efficiency of large high-speed turbine alternators." Presentation will be made during the AIEE summer convention at San Francisco, Calif., June 26–30, 1939. A biographical sketch of Mr. Savage appeared in the March issue, page 136.

ASA Lists Codes and Standards. The American Standards Association, joint agency of which the AIEE is a member-body, recently issued its annual indexed list of American standards and safety codes. The list includes about 400 nationally approved codes, standards, and specifications indexed alphabetically and also industrially by subject. Civil, mechanical, and electrical engineering, transportation, ferrous and nonferrous metallurgy, chemical industry, mining, petroleum, wood, pulp and paper, textiles, symbols and abbreviations are among the fields covered. More than 600 trade, technical, and governmental groups took part in developing these standards. Copies of the list may be obtained without charge from ASA headquarters, 29 West 39th Street, New York, N. Y.

Coolidge Receives Faraday Medal of the IEE at Springfield Meeting of North Eastern District

PRESENTATION of the Faraday Medal of The Institution of Electrical Engineers, Great Britain, to W. D. Coolidge (A'10, M'34) Director of the General Electric Company's Research Laboratory, Schenectady, N. Y., was a feature of the recent Springfield meeting of the Institute's North Eastern District. Dr. Coolidge is the third American to receive the Faraday Medal, previous recipients having been Elihu Thomson and Frank B. Jewett. Presentation of the medal and certificate to Dr. Coolidge was made by AIEE Past-President Gano Dunn who officiated in his capacity as Local Honorary Secretary of the IEE for the United States. The award to Dr. Coolidge was previously announced in ELECTRICAL ENGINEERING (March 1939, page 137), and the full text of Dr. Dunn's presentation address and of Dr. Coolidge's response may be found elsewhere in this issue.

Co-featured on the general session program Thursday morning, May 4, preceding the Faraday medal ceremony, were President John C. Parker of the AIEE and President C. W. Kellogg of the Edison Electric Institute. Selecting "socialization" as his topic, President Parker carefully defined the difference between "socialization" and "collectivization," pointing out that engineering in the broad sense is a pretty well socialized activity "by virtue of the way it penetrates and affects all walks of life." Dr. Parker urged each engineer to take his full place in civic affairs "so that folks will better know the engineer and the engineer better know the general public." Speaking on the topic "The Engineer as a Citizen," Mr. Kellogg further developed the same basic thought and presented some compelling facts and figures reflecting the current situation in the United States. These addresses are scheduled for publication in full text in an early issue of ELECTRICAL ENGINEERING. Present for the opening of the general session was Mayor R. L. Putnam of Springfield. Vice-President C. L. Dawes presided.

Traditions of the North Eastern District were upheld by the committee responsible for the Springfield meeting, in the program facilities for student participation, and in the industrial flavor of the general technical program. Something of a novelty in District meeting programs was what might be called the preview presentation of five papers scheduled for the forthcoming summer convention in San Francisco. The total registration figure of 439 is analyzed in the accompanying tabulation. Session attendance ranged from 65 to about 100, and averaged about 55; average for the two parallel student sessions was 95.

Supplementing the technical program, facilities for inspection trips to industries included the Bigelow Sanford Carpet Company, Thompsonville, Conn.; Stevens Paper Company, Westfield, Mass.; Chapman Valve Manufacturing Co., Indian Orchard, Mass.; Package Machinery Company, Springfield, Mass.; United States Armory, Springfield, Mass.; Westinghouse Electric and Manufacturing Co., East Springfield; Fisk Rubber Company, Chicopee, Mass.; Pratt and Whitney Aircraft Corp., Hartford, Conn. Some of these trips, especially that to the carpet plant, were enjoyed by women as well as men. Two highlights of the women's entertainment program were dinner and bridge at the Springfield Country Club Wednesday evening, and a "college cruise" Thursday that included visits to Mount Holyoke College, The Notch, Amherst, Massachusetts State College, Calvin Coolidge Memorial Bridge, Smith College; luncheon was served at Wiggins Old Tavern, Northampton. Climax of the entertainment program was the banquet held at the Hotel Kimball, Thursday evening, May 4, with Past Vice-President W. H. Timbie serving as toastmaster. Responding to invitation, President Parker and National Secretary Henline spoke briefly. President Parker called on the older Institute leaders to remember their own youth and "give way for the young men," and called on the younger men to take an increasingly active part in Institute affairs. Secretary Henline endorsed President Parker's idea and gave some brief citations of recent Institute activities—such as Houston meeting of the South West District, the Washington, D. C., Section student program, and New York Section joint student meeting—as an indication of the way this idea is being carried out.

Prize awards made at the banquet by Vice-President C. L. Dawes covering the preceding year were as follows: Best paper prize, C. W. LaPierre and A. P. Mansfield for their paper "Photoelectric Weft-Straightener Control," presented at the North Eastern District meeting, Lenox, Mass., in May 1938; best branch paper, divided between E. G. Schroeder of Rensselaer Polytechnic Institute for his paper "Investigation of Heat Dissipation and Temperature Rises in Underground Ducts," and P. P. Koliss and Joseph Ezen of Worcester Polytechnic Institute for their paper "Analysis of an Electron Tube-Controlled Induction Motor"; both papers presented at Lenox in May 1938.

Featured address of the evening was delivered by Dr. John L. Davis, professional lecturer and prominent minister of a New York Methodist Church. After amusing his audience for some time with a running fire of witty comments, speaking on the subject "dimensions of life" he gave further emphasis to the theme enunciated earlier in the evening by Doctor Parker, listing the early ages at which a host of prominent scientists made some of their most important discoveries and technical contributions The banquet was attended by 114 persons.

At the Springfield meeting, left to right: North Eastern District Secretary R. G. Lorraine, National Secretary H. H. Henline, Vice-President C. L. Dawes, Springfield Section Chairman W. O. Henschke, President J. C. Parker, and Editor G. R. Henninger

STUDENT TECHNICAL SESSIONS

Honors for technical session attendance went to the two parallel student sessions, with approximately 200 between them. To provide an outlet for the greatest possible number of student papers, the District committee on student activities under the chairmanship of Professor E. M. Strong of Cornell University arranged for the parallel sessions, one designated as a communication and measurement session and the other as a power session. As noted in the following listings, some 15 papers by 21 authors were presented:

Communication and Measurements Session—C. A. Lister, Tufts College, Chairman

An Instrument for the Measurement of Microvolts at Supersonic Frequencies, M. A. Schultt, Massachusetts Institute of Technology.

A Substitute for the Radio Range in Instrument Flight Training, R. B. Roe, Cornell University.

The Solution of Amplifier Circuits by Operational Methods, R. B. Rittenburg, Tufts College.

Frequency-Selective Feedback for Improvement of Acoustical Response of an Audio-Frequency Sound System, W. N. Brown, Jr., and E. W. Sheridan, Massachusetts Institute of Technology.

Stroboscopic Device for Sound-Wave Demonstration, W. K. Halstead and W. G. Tuller, Massachusetts Institute of Technology.

A Kinetic Power-Time Graph Demonstrator, E. L. Foster, Cornell University.

The "Glo-Relay," a New Method of Initiating Vapor Discharges, E. C. Dench, Worcester Polytechnic Institute.

Power Session—A. H. Sullivan, Jr., Cornell University, Chairman

Experimental Flux Plotting, W. C. Phillips, Jr., Tufts College.

A Thyratron Controlled Automatic Speed Governor, H. T. O'Neill and J. F. Clancy, Northeastern University.

A Study of Automobile Engine Ignition, R. F. Gilkeson, Cornell University.

Study of a Self-Excited A-C Generator, F. L. Miller and W. W. West, Brown University.

Breakdown Strength of Dielectrics in Presence of X-Rays, L. F. Kilham, Jr., Tufts College.

A Calorimetric Method for Determining Losses in Electrical Machines, H. S. Blauvelt, G. V. Pearson, and C. W. Thulin, Worcester Polytechnic Institute.

A Smoke Eliminator, Phil Smith, University of New Hampshire.

A Thyratron Method of Lighting Control for Small Theaters, C. R. Wischmeyer, Yale University.

Each of the two groups of papers were judged separately for participation in the District's program of student prize awards. From the communication and measurements group, the judges awarded first prize for effective presentation to W. N. Brown, Jr., and E. W. Sheridan; second prize to E. C. Dench. Of the power session group, first prize for presentation was awarded to L. F. Kilham, Jr.; second prize to H. T. O'Neill and J. F. Clancy. Subsequent review and examination of the student technical papers will provide the basis for the final District awards which probably will be announced at the 1939 District student conclave.

Conference on Student Activities

For the consideration of problems incidental to the conduct of student activities in the North Eastern District, a luncheon conference was held at the Highland Hotel, Springfield, Friday, May 5. Last year this group had, after considerable discussion, decided in favor of two parallel sessions for the presentation of student technical papers. Inasmuch as the two sessions at Springfield were held after this conference, there was no opportunity for discussing the results of the practical application of that decision. However, the notable success of the Springfield student program subsequently spoke for itself. An exchange of comments pertaining to 1940, when the annual summer convention of the Institute will be held at Swampscott with the consequent elimination of the District meeting for that year, led to the tentative decision to hold a joint student conference probably May 3, 1940. Several schools have offered to act as host for such a conference, but no decision was made. Conversation points toward Worcester Polytechnic Institute.

All 16 of the student branches in the North Eastern District were represented, by a total of 33 faculty or enrolled student members of which the following constituted the official delegates:

Student Branch Counselors and Alternates

C. W. Henderson, Syracuse University, Syracuse, N. Y.

Victor Siegfried, Worcester Polytechnic Institute, Worcester, Mass.

L. C. Holmes, Rensselaer Polytechnic Institute, Troy, N. Y.

A. G. Conrad, Yale University, New Haven, Conn.

R. O. Buchanan, University of Vermont, Burlington, Vt.

F. N. Tompkins, Brown University, Providence, R. I.

J. D. Cobine, Harvard University, Cambridge, Mass.

G. S. Brown, Massachusetts Institute of Technology, Cambridge, Mass.

Analysis of Registration at Springfield

Classification	Location: Springfield Section	District 1*	Other Districts	Totals
Members	34	157	37	228
Students	0	153	3	156
Men Guests	8	20	4	32
Women Guests	10	11	2	23
Totals	52	341	46	439

* Outside Springfield.

E. A. Walker, Tufts College, Tufts College, Mass.

R. G. Porter, Northeastern University, Boston, Mass.

E. M. Strong, Cornell University, Ithaca, N. Y.

G. J. Fiedler, Union College, Schenectady, N. Y.

W. B. Hall, Rhode Island State College, Kingston.

L. W. Hitchcock, University of New Hampshire, Durham, N. H.

A. S. Hill, University of Maine, Orono, Maine.

Student Branch Chairman and Alternates

J. Leo Raesler, Syracuse University, Syracuse, N. Y.

H. L. Anderson, Worcester Polytechnic Institute, Worcester, Mass.

L. D. Runkle, Rensselaer Polytechnic Institute, Troy, N. Y.

J. G. Stephenson, Yale University, New Haven, Conn.

E. C. Bailey, University of Vermont, Burlington, Vt.

W. W. West, Brown University, Providence, R. I.

R. M. Hutchinson, Harvard University, Cambridge, Mass.

R. B. Lawrence, Massachusetts Institute of Technology. Cambridge.

M. L. Greenough, Tufts College, Tufts College, Mass.

Crawford Adams, Cornell University, Ithaca, N. Y.

D. P. Campbell, Union College, Schenectady, N. Y.

H. G. Crook, Rhode Island State College, Kingston.

Phil Smith, University of New Hampshire, Durham, N. H.

H. M. Kenney, University of Maine, Orono, Maine.

M. J. Mulhern, Clarkson College of Technology, Potsdam, N. Y.

Others among the total of 39 persons attending the conference included Past-Presidents Charles F. Scott and D. C. Jackson, National Secretary H. H. Henline, Vice-President C. L. Dawes, Chairman E. M. Strong of the District committee on student activities, District Secretary R. G. Lorraine, Editor G. R. Henninger, Burton Hall of Rhode Island State College, and E. R. McKee of the University of Vermont.

District Executive Committee Meeting

A luncheon-business session of the District executive committee was held Wednesday, May 3. Chairman Strong of the District committee on student activities reported briefly for his special committee that has been studying the matter of a new and more satisfactory basis for the rating of student technical papers. The committee long has contended that methods of rating applicable to formal technical program papers are neither satisfactory nor equitable for the grading of student technical papers, which are intended to accomplish a fundamentally different purpose. Tentatively, Professor Strong's committee recommended that for student papers, 10 points be allowed for introduction; 50 points for speaking technique, including personal characteristics and manner of delivery; 50 points for style, including the speaker's organization of material; 10 points for summary and conclusion; 20 points for manner and effectiveness in handling discussion. Pursuant to favorable action by the executive committee, Professor Strong's committee is to report in detail to Chairman R. W. Sorensen of the AIEE Committee on Student Branches, in the hope that the subject will be discussed at the annual conference of officers, delegates and members to be held in conjunction with the summer convention in San Francisco next month. Another problem to be submitted for summer convention discussion is the matter of the District student prizes particularly with respect to papers prepared by graduate students, where so few papers are available in the ordinary year that effective competition or equitable competitive rating is a difficult matter. Provisions were made for an augmented District co-ordinating committee to meet May 13 at the New Ocean House, Swampscott, Mass., with officers of the Boston and Lynn Sections and hotel authorities for the purpose of perfecting preliminary plans for the 1940 summer convention scheduled to be held at Swampscott. (This meeting was held as scheduled.)

Official attendants at the meeting included the following:

C. L. Dawes, vice-president, AIEE
R. G. Lorraine, secretary, North Eastern District
E. M. Strong, chairman, North Eastern District committee on student activities
W. O. Henschke, chairman, Springfield Section
W. W. Cotner, chairman, Ithaca Section
F. A. Faron, chairman, Connecticut Section
C. W. LaPierre, representing Schenectady Section
J. G. Patterson, chairman, Boston Section
C. E. Tuites, secretary, Rochester Section
L. Wetherill, chairman, Pittsfield Section

Others in attendance included Past Vice-President A. C. Stevens of Schenectady, Director K. B. McEachron of Pittsfield, Student Counselor Victor Siegfried of Worcester Polytechnic Institute, Past Chairman F. N. Tompkins of the District committee on student activities, National Secretary H. H. Henline and Editor G. R. Henninger of New York.

A group of student authors and others who participated in the student sessions at the Springfield meeting

Future Meetings of Other Societies

American Association for the Advancement of Science. June 19–24, Milwaukee, Wis.

American Institute of Mining and Metallurgical Engineers. 151st general meeting, July 10–13, San Francisco, Calif.

American Physical Society. 228th meeting, June 23–24, Princeton, N. J.

229th meeting, June 28–30, Stanford University, Calif.

American Society for Testing Materials. 42d annual meeting, June 26–30, Atlantic City, N. J.

American Society of Civil Engineers. Annual convention, July 26–29, San Francisco, Calif.

American Society of Heating and Ventilating Engineers. Semiannual meeting, July 4–6, Mackinac Island, Mich.

American Society of Mechanical Engineers. Semiannual meeting, July 10–15, San Francisco, Calif.

Fall meeting, September 4–8, New York, N. Y.

Illuminating Engineering Society. 33d annual convention, August 21–25, San Francisco, Calif.

Institute of Radio Engineers. National convention, June 27–30, San Francisco, Calif.

Fortieth annual convention, September 20–23, New York, N. Y.

International Conference on High-Voltage Systems (CIGRE). Tenth meeting, June 29–July 8, Paris, France.

Society for the Promotion of Engineering Education. 47th annual meeting, June 19–23, The Pennsylvania State College, State College, Pa.

Industrial Research Institute Election. Election of new officers and members of its executive committee has been announced by the Industrial Research Institute, as follows: *Chairman*—H. W. Graham, Jones and Laughlin Steel Corporation, Pittsburgh, Pa.; *Vice-Chairman*—H. B. Hoover, The Hoover Company, Chicago, Ill.; *Members*—L. W. Wallace, The Crane Company, Chicago, Ill.; F. W. Blair, Proctor and Gamble Company, Ivorydale, Ohio. The committee is composed of executives in charge of research laboratories. The Industrial Research Institute was formed in 1938 to provide research men in industry with an organization in which they could exchange information on laboratory organization, administration, and other problems. (*EE, Oct. '38, p. 429*)

ASCE to Hold International Meeting. The Institution of Civil Engineers of Great Britain and the Engineering Institute of Canada will be guests of the American Society of Civil Engineers at its Fall meeting, to be held in New York, N. Y., September 1939, in connection with the New York World's Fair. A comprehensive program of technical meetings, social events, inspections, and sight-seeing has been arranged for the meeting, which will open September 4. The technical and some of the social aspects of the program will center around Columbia University, while its supplementary features will be in connection with the World's Fair.

Section and Branch Activities

Annual Report for 1938–39

THE following constitutes the annual report on Institute Section and Branch activities for the fiscal year which ended April 30, 1939. Similar information for three preceding fiscal years appeared in ELECTRICAL ENGINEERING for June 1938, pages 263–6; June 1937, pages 762–5; June 1936, pages 752–4.

Present members of the Sections committee and the committee on Student Branches, which supervise the two important divisions of Institute activities covered by this report, are: Sections—H. H. Race, *chairman*, M. S. Coover, W. M. Dann, O. W. Holden, E. T. Mahood, I. Melville Stein, W. H. Timbie, and, *ex-officio*, the chairmen of all Sections of the Institute; Student Branches—R. W. Sorensen, *chairman*, R. H. Dearborn, E. E. Dreese, W. C. DuVall, G. A. Irland, F. Ellis Johnson, C. W. Ricker, Charles F. Scott, E. M. Strong, and, *ex-officio*, all Student Branch counselors.

Table I. Section Meetings Held During Year Ending April 30, 1939

Section	AIEE Members August 1937	AIEE Members August 1938	Meetings During Year Number	Meetings During Year Average Attendance	Meetings During Year Average Attendance as Per Cent of Membership, August 1938
Akron	63	76	8	63	83
Alabama	48	39	4	56	144
Baltimore	188	201	11	163	81
Boston	409	411	8	215	52
Central Indiana	135	123	7	147	119
Chicago	674	697	6	291	42
Power group			5	105	
Industrial group			3	59	
Cincinnati	175	182	10	218	120
Study discussion group			7		
Cleveland	285	300	9	190	63
Technical group			5	66	
Mansfield Division*			3		
Columbus	79	87	5	214	246
Connecticut	266	267	9	143	54
Dallas	101	114	9	132	116
Denver	160	168	8	85	51
East Tennessee	76	102	9	46	45
Erie	63	67	9	58	87
Florida	66	68	1	128	188
Fort Wayne	86	88	8	116	132
Georgia	83	97	8	185	191
Houston	89	116	11	174	150
Iowa	53	50	7	62	124
Ithaca	54	47	8	70	149
Kansas City	122	124	9	115	93
Lehigh Valley	197	193	9	96	50
Los Angeles	470	486	8	139	29
Louisville	49	50	8	86	172
Lynn	128	130	11	477	366
Technical lectures			5	450	
Madison	64	64	5	174	272
Mansfield*			1	136	
Memphis	53	53	11	56	106
Mexico	67	66	4	74	112
Michigan	353	342	9	150	44
Round table discussions			5	27	
Milwaukee	268	297	7	318	107
Minnesota	88	83	8	120	145
Power committee			1	55	
Montana	39	39	3	94	241
Muscle Shoals	33	40	13	44	110
Nebraska	55	58	8	71	122
New Orleans	64	78	8	89	114
New York	3,308	3,346	5	375	11
Power group			11	267	
Communication group			8	350	
Transportation group			3	133	
Basic science group			2	138	
Illumination group			3	308	
Niagara Frontier	218	205	7	290	141
North Carolina	77	78	1	148	190
Oklahoma City	97	106	11	202	191
Philadelphia	571	580	8	212	37
Pittsburgh	464	503	8	188	37
Pittsfield	150	167	8		
Technical meetings			6		
Colloquium meetings			4		
Portland	119	125	11	192	154
Transmission and distribution committee			8	47	
Communication committee			1	55	
Providence	93	95	7	54	57
Rochester	92	94	11	115	122
Communication group			3	33	
Power group			2	16	
St. Louis	240	247	10	82	33
San Antonio	35	37	8	45	122
San Diego†			4	36	
San Francisco	442	457	10	144	32
Technical meetings			6	70	
Saskatchewan	25	25	8	47	188
Schenectady	397	428	13	247	58
Technical discussion meetings			4		
Seattle	144	156	10	125	80
Power group			1	35	
Electronics group			1	68	
Sharon	77	80	9	126	157
Spokane	55	62	8	148	238
Springfield	68	57	9	69	121
Syracuse	73	73	8	220	301
Toledo	78	78	8	62	79
Toronto	309	348	13	150	42
Discussion group			2	124	
Tulsa	61	85	8	140	166
Urbana	58	65	9	144	221
Utah	59	56	9	113	202
Vancouver	99	98	11	62	63
Virginia	92	92	1	80	87
Washington	256	288	10	155	54
Technical sessions			2	80	
Wichita	27	33	10	46	139
Worcester	67	69	9	158	229
Total	67	13,054	13,539		
Total number of meetings					635
Total attendance					85,692

* Mansfield division of Cleveland Section became Mansfield Section March 6, 1939.
† Organized January 18, 1939.

Table II. Section Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1937	1938	1939
Number of Sections	62	65	67
Number of meetings held	621	624	635
Average number of meetings	10.0	9.6	9.5
Total attendance	74,950	110,148	85,692
Average attendance per meeting	121	177	135

Section Activities

Two new Sections were organized during the year, San Diego in January, and Mansfield in March, bringing the total number to 67. A Mansfield division of the Cleveland Section had previously been organized, and had held three meetings while securing a sufficient number of new members to meet the requirement for a Section.

All of the Sections were active during the past year. The total number of meetings reported to headquarters was 635, the largest number ever reported, which indicates that the increase in activity noted in the two fiscal years immediately preceding has been maintained.

President Parker visited many Sections, and his addresses were enthusiastically received.

The name of the Detroit-Ann Arbor Section was changed to Michigan Section with no change in territory. The San Francisco Section Territory was expanded to include six counties in western Nevada.

The group and special meeting plans inaugurated in previous years by many Sections were continued with excellent success, and a few new groups were organized. The meetings of these groups are reported in table I.

The Cleveland Section organized a technical group which held five meetings. The Philadelphia Section organized a communication group, and also inaugurated a weekly luncheon club. The name of the electrophysics group of the New York Section was changed to basic science group.

Table III. Prizes Awarded by Sections

Section	Number of Papers Presented	Amounts of Awards
Houston	2	$10, $5
Iowa	8	$25 and Standard Handbook
Los Angeles	6	$15.00
Lynn	8	$15, $10, $5
	8	$15, $10, $5
Minnesota	4	$15, $10, $5, $5
New Orleans	2	Attendance prize
New York	6	$25, $10
Oklahoma City		$15, $10, $5
Pittsfield*	6	$15, $10
Portland	4	$10
St. Louis	5	$15, $10, $5
San Francisco	3	$10
Schenectady*	6	$25 (divided)
Toronto	4	Two prizes
Tulsa		Three prizes
Utah	4	$10

* Two meetings in competition between Sections.

Table IV. Branch Meetings Held During Year Ending April 30, 1939

Branch	Meetings During Year: Number	Average Attendance	Approximate Number of Talks by Students
Akron, University of	9	27	5
Alabama Polytechnic Institute	7	34	2
Alabama, University of	13	17	9
Arizona, University of	16	9	10
Arkansas, University of	16	40	11
Armour Institute of Technology	12	44	
British Columbia, University of	18	23	21
Brooklyn, Polytechnic Institute of			
Day Division	9	61	1
Evening Division	4	34	4
Brown University	9	45	
Bucknell University	14	27	4
California Institute of Technology	22	38	4
California, University of	26	48	3
Carnegie Institute of Technology	26†	49	22
Case School of Applied Science	18†	62	23
Catholic University of America	5	14	2
Cincinnati, University of	4	61	6
Clarkson College of Technology	7	30	
Clemson Agricultural College	7	27	10
Colorado State Agricultural College	7	15	3
Colorado, University of	12	56	3
Columbia University	7	27	2
Cooper Union			
Day Division	7	23	2
Evening Division	9	20	6
Cornell University	5	36	4
Denver, University of	8	40	
Detroit, University of	5	41	
Drexel Institute	16	30	3
Duke University	12	20	9
Florida, University of	12	28	1
George Washington University	8	34	3
Georgia School of Technology	6	76	
Harvard University	5	72	
Idaho, University of	9	47	1
Illinois, University of	6	85	2
Iowa State College	11	83	
Iowa, University of	16	36	17
Johns Hopkins University	12	23	10
Kansas State College	13†	97	19
Kansas, University of	9	41	5
Kentucky, University of	19	125	3
Lafayette College	6	16	4
Lehigh University	3	68	1
Lewis Institute	8	32	
Louisiana State University	5	24	4
Louisville, University of	10	18	8
Maine, University of	9	15	4
Marquette University	7	54	4
Maryland, University of	8	26	7
Massachusetts Inst. of Technology	14	53	5
Michigan Col. of Mining & Technology	3	43	1
Michigan State College	15	28	
Michigan, University of	8	95	
Milwaukee School of Engineering	7	53	7
Minnesota, University of	6	82	
Mississippi State College	5	46	1
Missouri School of Mines & Metallurgy	9	43	4
Missouri, University of	9	34	4
Montana State College	27†	30	84
Nebraska, University of	16	45	12
Nevada, University of	10	41	2
Newark College of Engineering	2	48	
New Hampshire, University of	11	33	3
New Mexico State College*	7	18	6
New Mexico, University of	7	20	5
New York, College of the City of			
Day Division	10	48	
Evening Division			
New York University			
Day Division	4	32	1
Evening Division			
North Carolina State College	13	41	13
North Dakota State College	6	12	4
North Dakota, University of	13	12	7
Northeastern University	15	56	3
Northwestern University	7	30	
Notre Dame, University of	8	39	3
Ohio Northern University	7	30	3
Ohio State University	11	51	6
Ohio University	2	18	
Oklahoma A. & M. College	10	143	7
Oklahoma, University of	10	54	6
Oregon State College	9	62	7
Pennsylvania State College	5	106	
Pennsylvania, University of	8	24	7
Pittsburgh, University of	14†	96	8
Porto Rico, University of	7	36	
Pratt Institute	14	43	4
Princeton University	5	15	5
Purdue University	17	250	
Rensselaer Polytechnic Institute	4	95	
Rhode Island State College	10	33	2
Rice Institute	1	6	2
Rose Polytechnic Institute	4	25	6
Rutgers University	3	29	
Santa Clara, University of	10	25	8
South Carolina, University of	12	26	
South Dakota State College	10	18	3
South Dakota State School of Mines	13	35	
Southern California, University of	16	18	6
Southern Methodist University	8	36	3
Stanford University	10	30	4
Stevens Institute of Technology			
Swarthmore College	8	11	
Syracuse University	19	36	13
Tennessee, University of	5	39	
Texas A. & M. College	12	44	7
Texas Technological College	14	17	6
Texas, University of	9	69	1
Tufts College	8	30	5
Tulane University	9	27	8
Union College	4	51	
Utah, University of	11	32	4
Vermont, University of	11	24	3
Villanova College	6	11	2
Virginia Military Institute	10†	42	13
Virginia Polytechnic Institute	18	75	13
Virginia, University of	3	25	2
Washington, State College of	14	47	6
Washington, University of	11	88	11
Washington University	8	42	2
West Virginia University	17	37	112
Wisconsin, University of	3	41	
Worcester Polytechnic Institute	9	87	2
Wyoming, University of	9	13	1
Yale University	8	18	
Total	120		725
Total number of meetings			1,190
Total attendance			53,380

* Authorized by Executive Committee, December 16, 1938.
† Attendance at all or nearly all meetings required by faculty, as indicated in questionnaire distributed by chairman of committee on Student Branches.

Table V. Branch Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1937	1938	1939
Number of Branches	119	120	120
Number of meetings held	1,363	1,334	1,190
Average number of meetings	11.5	11.1	9.9
Total attendance	46,121	60,446	53,380
Average attendance per meeting	33.8	45.3	44.8
Number of student talks	1,130	897	725

The Michigan Section held a series of round-table discussions.

The Portland Section held classes in symmetrical components. The power group of the New York Section offered courses in structural planning and design, electrical engineering review, engineering economics and practice, law for engineers, public speaking, television, and diathermy and X rays.

The Pittsfield and Schenectady Sections held their tenth annual competition in two joint meetings, one in each city, with three speakers representing each Section at each meeting. Prizes of $15 and $10 were awarded at each meeting.

Brief information regarding prizes offered by a considerable number of Sections is given in table III.

The Toronto Section continued its practice of holding meetings of the discussion group and the technical discussion group immediately preceding a large majority of the regular Section meetings.

The Cincinnati Section continued with good success its meetings of the study-discussion group for consideration of articles in ELECTRICAL ENGINEERING dealing with professional development and engineering education.

The executive committee of the New York Section requested that the members of the Section indicate on a return post card their reactions to a proposed amendment to the state education law tending to make mandatory six years of scholastic training for licensing as a professional engineer. Eighty-eight per cent of the approximately 1,700 Section members who had voted by May 15 were opposed to the proposed amendment.

The committee on safety wrote the Sections suggesting that each have presented a paper dealing with accident prevention or remedial measures after electrical shock. The replies indicated that in general the Sections were making arrangements to carry out the suggestion.

Tables I, II, and III contain detailed information on Section activities. Table VI gives a comprehensive record of co-operation between Sections and Branches.

BRANCH ACTIVITIES

A new Branch organized at the New Mexico State College restored the total number to 120, after the University of North Carolina Branch was discontinued due to a consolidation of the engineering school with that at North Carolina State College.

The total number of Branch meetings was materially below the number reported for each of the two preceding fiscal years. Only one Branch failed to report any activity. Eighteen Branches held more than 15 meetings each, 61 held from 8 to 15, 32 held from 4 to 7, and 9 held fewer than 4 meetings.

President Parker visited a considerable number of Branches, some separately, and in a few cases he spoke at joint meetings attended by representatives of several Branches. He also attended the dinner meeting held in connection with the conference on student activities of the Middle Eastern District, in Washington, D. C.

On a questionnaire sent to the Branches by the committee on Student Branches, all except 6 of 62 replies indicated voluntary attendance and participation in the activities.

Although a large majority of the Branches had some papers presented by students, the total number of such papers was far below the number in each of the two preceding fiscal years. This important phase of Branch activity should receive increased attention.

Of 1,564 enrolled students whose terms, according to Institute records, were expected to expire on April 30, 1939, 849 or about 54 per cent applied for admission as Associates. Some of the students were eligible to continue enrollment because they had remained

Table VI. Section or Joint Section and Branch Meetings With Active Student Participation

Sections	Schools	Date	Student Talks	Attendance
Los Angeles	California Institute of Technology			
	University of Southern California	5/10/38	6	105
Cincinnati	University of Cincinnati	5/12/38	3	65
New Orleans	Louisiana State University	5/13/38	3	79
Oklahoma City and Tulsa	University of Arkansas			
	Oklahoma A. & M. College			
	University of Oklahoma	5/13/38	3	110
Portland	Oregon State College	5/14/38	4	90
St. Louis	Missouri School of Mines & Met.			
	University of Missouri			
	Washington University	5/20/38	5	88
Utah	University of Utah	5/23/38	5	35
Nebraska	University of Nebraska	10/19/38		153
Portland	Oregon State College	11/15/38		93
San Antonio	University of Texas	12/5/38	1	83
Toronto	University of Toronto	12/9/38	4	70
New Orleans	Tulane University	1/20/39	2	75
Dallas	Southern Methodist University	1/31/39		122
Nebraska	University of Nebraska	2/9/39		80
Vancouver	University of British Columbia	3/6/39	4	37
Kansas City	University of Kansas	3/16/39	1	64
Houston	Rice Institute			
	Texas A. & M. College	3/22/39	2	76
Minnesota	University of Minnesota	4/18/39	4	55
Iowa	Iowa State College			
	University of Iowa	4/20/39	8	82
Central Indiana	Purdue University	4/21/39		175
Spokane	University of Idaho			
	Washington State College	4/27/39	1	67
San Francisco	University of California			
	University of Santa Clara			
	Stanford University	4/21/39	3	100
Totals—20 Sections, 30 Branches			59	1,904

Table VII. Conferences on Student Activities

District or Section	Location	Date
7	Kansas State College, Manhattan	5/7/38
1	Lenox, Mass. (North Eastern District meeting)	5/20/38
8 and 9, University of British Columbia	Portland, Ore. (Pacific Coast convention)	8/9/38
2	Washington, D. C.	11/4–5/38
4	Miami, Fla. (Southern District meeting)	11/28/38
Pittsburgh Section	Pittsburgh, Pa.	1/10/39
7	Houston, Tex. (South West District meeting)	3/19/39
6	Laramie, Wyo.	3/21–22/39

Table VIII. Student Conventions

Sponsor (District, Section, or Branch)	Location	Date	Number of Student Papers
7	Kansas State College, Manhattan	5/6–7/38	22
1	Lenox, Mass. (North Eastern District meeting)	5/19–20/38	6
8 and 9, University of British Columbia	Portland, Ore. (Pacific Coast convention)	8/10–11/38	10
4	Miami, Fla. (Southern District meeting)	11/28/38	6
Pittsburgh Section	Pittsburgh, Pa.	1/10/39	4
7	Houston, Tex. (South West District meeting)	4/18–19/39	14
6	University of Wyoming, Laramie	4/21–22/39	9
3 and New York Section	Cooper Union, New York, N. Y.	4/27/39	6
Purdue University Branch	Lafayette, Ind.	4/29/39	2

in school. For the preceding fiscal year, the corresponding figures were 1,474, 703, and about 48 per cent.

Students have continued their active participation in the Pacific Coast convention and District meeting programs. Student sessions were held as follows: North Eastern District meeting, Lenox, Mass., May 18–20, 1938, 1 session, 6 papers; Pacific Coast convention, Portland, Ore., August 9–12, 1938, 2 sessions, 10 papers; Southern District meeting, Miami, Florida, November 28–30, 1938, 1 session, 6 papers; South West District meeting, Houston, Texas, April 17–19, 1939, 3 sessions, 14 papers.

The committee on safety, with the approval of the committee on Student Branches, wrote the counselors of the Student Branches suggesting that each Branch have presented a paper dealing with the prevention of accidents or remedial measures after electrical shock. The replies indicated much interest in carrying out the suggestion.

Tables IV and V contain information on Branch meetings, table VI gives a record of co-operation between Sections and Branches, and tables VII and VIII present summarized data on student conferences and conventions.

AIEE National Prize Awards Announced for 1938 Papers

After consideration of all eligible papers, the AIEE committee on award of Institute prizes has announced the national prize awards for papers presented during 1938. The award for best paper in public relations and education is the first since 1936, and in accordance with the provisions of the present rules, the committee considered all papers under this classification presented since that year. The prizes will be presented during the Institute's combined summer and Pacific Coast convention, San Francisco, Calif., June 26–30. The committee consists of H. S. Osborne, *chairman*, J. W. Barker, E. C. Crittenden, and I. Melville Stein.

Papers and their authors receiving awards in the various classifications are as follows:

BEST PAPERS

Best Paper in Engineering Practice. This prize was awarded to C. F. Wagner (A'20, M'27) for his paper "Unsymmetrical Short Circuits on Water-Wheel Generators Under Capacitive Loading," published in ELECTRICAL ENGINEERING (AIEE TRANSACTIONS) for November 1937, pages 1385–95, and presented at the winter convention, New York, N. Y., January 24–28, 1938.

Honorable mention was made of the following papers: "A Carrier Telephone System for Toll Cables," by C. W. Green (A'1 , M'26) and E. I. Green (A'23, M'30) presented at the winter convention, New York, N. Y., January 24–28, 1938, and published in the 1938 TRANSACTIONS (May section) pages 227–36; "The PCC Street Car," by C. F. Hirshfeld (A'05, F'36, deceased) presented at the winter convention, New York, N. Y., January 24–28, 1938, and published in the 1938 TRANSACTIONS (February section) pages 61–66.

Best Paper in Theory and Research. This prize was awarded to K. S. Wyatt (A'32), D. L. Smart (A'37), and J. M. Reynar, for their paper "Mechanical Uniformity of Paper-Insulated Cables," published in the 1938 TRANSACTIONS (March section) pages 141–54, and presented at the winter convention, New York, N. Y., January 24–28, 1938.

Honorable mention was made of the paper "Amplitudes of the Magnetomotive Force Harmonics for Fractional Slot Windings," by J. F. Calvert (A'27, M'35) presented at the summer convention, Washington, D. C., June 20–24, 1938, and published in the 1938 TRANSACTIONS, pages 777–84.

Best Paper in Public Relations and Education. This prize was awarded to R. W. Sorensen (A'07, F'19) for his paper "The Economic Status of the Engineer," published in the 1938 TRANSACTIONS, pages 786–9, and also in ELECTRICAL ENGINEERING, July 1938, pages 281–85, and presented at the summer convention, Washington, D. C., June 20–24, 1938.

INITIAL PAPER

Prize for initial paper was awarded to S. J. Rosch (A'15) for his paper "The Current-Carrying Capacity of Rubber Insulated Cables," published in the 1938 TRANSACTIONS (March section) pages 155–67, and presented at the winter convention, New York, N. Y., January 24–28, 1938.

Honorable mention was made of the following papers: "Noise Co-ordination of Rural Power and Telephone Systems," by H. W. Wahlquist (M'36) and T. A. Taylor (A'30, M'36) published in the 1938 TRANSACTIONS (November section) pages 613–20, and presented at the winter convention, New York, N. Y., January 24–28, 1938; "A Symbolic Analysis of Relay and Switching Circuits," by Claude E. Shannon, published in the 1938 TRANSACTIONS, pages 713–23, and presented at the summer convention, Washington, D. C., June 20–24, 1938.

BRANCH PAPER

Prize for Branch paper was awarded to John L. C. Lof for his paper "A Method for Determining the Efficiencies of Small Motors From the Heat Due to Eddy Currents."

Honorable mention was made of the paper "An Investigation of Some of the Properties of a Non-Linear Circuit," by R. W. Warburton and W. W. Murdoch.

Awards being made by the various AIEE Districts for 1938 papers will be announced in future issues, as this information becomes available.

Physics Meeting in Switzerland. Members of AIEE are invited to attend an International Meeting on Physics which will be held in Zurich, Switzerland, September 4–16, 1939, in connection with the Swiss National Exhibition. The meeting, which is sponsored by the Federal Institute of Technology of Switzerland, and the Physical Society of Zurich, will include a two-day program on television, the same time as the second international television meeting.

Current Items From American Engineering Council

Questionnaire on Patents for Engineers and Inventors

As announced in the February 1939 issue (page 88) American Engineering Council has undertaken a factual inquiry into the American patent system in co-operation with the National Association of Manufacturers and the National Industrial Conference Board. It is considered of primary importance in this inquiry to ascertain whether patents have had their intended usefulness to the engineer as an inventor. Has he been able successfully to put to use his inventions and derive a satisfactory benefit from them? Does the patent provide him with a positive and effective means to assert his claims against others who have devised similar technical improvements? What channels have been made available to him through the patent to convey title to his invention to those who can make best use of it, and what obstacles has he encountered?

To obtain a broad and representative cross section of the experience of engineers at large, a questionnaire has been prepared by F. E. Raymond, director of the joint patent inquiry. Some of the more significant questions included are:

1. How have you put your patents to use?
2. What are the principal reasons for the non-use of your patents?
3. Have you encountered any premeditated opposition from others to the working or use of your patents?
4. How many of your patents have been involved in litigation?
5. Have any of your patent applications been denied?
6. What rewards or satisfactions (other than monetary) have come to you through your patented inventions?

All AIEE members who have had any experience with the patent system are urged to request a copy of this questionnaire from American Engineering Council, 744 Jackson Place, Washington, D. C., fill in the answers to the various questions, and return it promptly to Council headquarters in order that the joint patent inquiry may have available the broadest possible cross section of experiences of electrical engineers. All replies will be treated strictly confidentially.

Federal Public Works Agencies Combined by Presidential Order

Exercising the authority granted him under the new reorganization act, President Roosevelt on April 25 submitted to Congress the first of three plans for re-grouping the functions of various agencies of the Federal Government, to become effective in 60 days unless disapproved, as a whole, by a majority vote of both the Senate and the House of Representatives within that period, or unless Congress in the meantime adjourns. Since the House on May 3 voted down a resolution of disapproval, only an early adjournment could prevent its taking effect on June 24. To the Federal Works Agency proposed by the President will be transferred the functions and personnel of "those agencies of the Federal Government dealing with public works not incidental to the normal work of other departments, and which administer federal grants or loans to state and local governments, or other agencies, for the purpose of coustruction."

Transferred to the Federal Works Agency will be the Bureau of Public Roads, now in the Department of Agriculture; the Public Buildings Branch of the Procurement Divi-

sion, Treasury Department (which designs and supervises construction of federal buildings in all parts of the country); the Branch of Building Management of the National Parks Service, Department of Interior, which selects sites for and determines the order of construction of public buildings in the District of Columbia; the United States Housing Authority, now in the Department of the Interior (slum-clearance); the Public Works Administration; and the Works Progress Administration (both independent agencies set up on a temporary basis). Still unchanged is the present supervision of the Corps of Engineers over river and harbor improvements and flood control works, since this agency was specifically exempted by the reorganization act.

Heading the new agency will be a Federal Works Administrator, to be appointed by the President with the advice and consent of the Senate, at a salary of $12,000 per year, and an Assistant Federal Works Administrator at $9,000. In general, the present heads of the units transferred to the agency will be retained and will report to the Administrator. Any personnel in excess of the needs of the new agency will be transferred to other government posts or given a preferred status on eligible lists for future employment.

The general plan for reorganization, as set forth in the President's message, envisions two additional new agencies to be known as the Federal Security Agency and the Federal Loan Agency. The present major independent agencies of the government (except those exempted by law) will be attached either to one of these three, to one of the ten existing executive departments, or, in a few instances, to the White House executive office.

Standards

The Place of the IEC in Electrical Standardization

In an effort to acquaint the Institute membership more fully with the standards activities of the Institute, the AIEE standards committee, through its newly appointed subcommittee on publicity, has initiated a series of articles for publication in ELECTRICAL ENGINEERING. The first, published in the April issue, discussed the interrelations between the Standards activities of the AIEE and of the American Standards Association. In the May issue, the appointment of four co-ordinating committees of the standards committee was announced, and one of these four committees announced its objectives and tentative plans of action. In the following item, the work of the International Electrotechnical Commission and its relationship to the Standards activities of the Institute are discussed. It was prepared by J. W. McNair (A'25) secretary, United States National Committee of the IEC, and electrical engineer, American Standards Association.

The International Electrotechnical Commission (IEC) was founded in 1906 as a result of the resolution passed by the chamber of government delegates at the International Electrical Congress in St. Louis, Mo., in 1904. Its object is to provide permanent machinery whereby any international problem of standardization in the electrical field may be given continuous and effective study. It is composed of 26 national committees which are representative of all sections of electrical industry in their respective countries. The IEC undertakes problems of electrical standardization when requested to do so by the electrical industry of any country speaking through the medium of its national committee.

The IEC is an example of the benefit of giving continuous study to difficult problems as against the intermittent study formerly given by infrequent international conferences, especially when the problems are complicated by constantly changing factors and by the economic conditions in the different nations. Much of the work of the IEC is devoted to the preparation of internationally acceptable recommendations used to facilitate international trade in electrical machinery and apparatus. These recommendations enable purchasers to compare on a uniform basis offers to supply apparatus regardless of from what country the bids are received.

Much work has been done also on questions of systems of electrical units and the naming of units and magnitudes, standardization of letter and graphical symbols in the electrical field, and the preparation of an international electrotechnical vocabulary.

The recommendations of the IEC represent an international consensus of opinion and are accepted by the national committees for international purposes. The national committees when accepting these recommendations are under no obligation to adopt these rules as their own national standards. It is understood, however, that they will use their best efforts to harmonize their national requirements with IEC recommendations in so far as conditions permit.

The work of the IEC is carried forward by 27 permanent advisory committees (see table). These committees are under the administrative direction of a particular national committee, known as the secretariat, which accepts this responsibility. The subjects cover various types of electrical machinery and apparatus, insulating oils and insulating materials, measuring instruments, etc., and also include steam, hydraulic, and internal-combustion prime movers. The work has resulted to date in the approval of 24 IEC recommendations. Some of these have been revised several times in the effort to keep them up to date. In addition, there is a series of dimensional specifications for lamp bases and sockets and gauges therefor. Most of the IEC publications and reports may be obtained from the American Standards Association, 29 West 39th Street, New York, N. Y.

Plenary meetings of the IEC are held every three years in the different countries. At these meetings all of the advisory committees meet which have active work before them. In the intervals between plenary meetings, groups of five or six advisory committees having extremely active work before them meet twice each year. In 1939 such meetings will be held in New York in September and in Zurich, Switzerland, in October, the last plenary meeting of the IEC having been held in Torquay, England, in June 1938.

The meetings in New York will be held September 5 to 8 and will cover the following subjects: transformers, hydraulic turbines, switchgear, internal-combustion engines, electric welding, insulation co-ordination. The meetings in Zurich will be held October 2 to 5 and will cover the following subjects: graphical symbols, aluminium, electric-traction equipment, radio communication, measuring instruments, electronic devices.

The administrative affairs of the Commission are conducted by an executive group, known as the committee of action, which ordinarily meets once a year although it is empowered to meet twice a year if necessary. Between plenary meetings the committee of action is empowered to authorize the publication of IEC recommendations which have been submitted to, and voted favorably upon by, the national committees under a six-months rule. The Commission maintains a central office in London to manage its affairs. This office is under the direction of Charles le Maistre (A'12) who has been general secretary of the IEC since its organization

THE UNITED STATES NATIONAL COMMITTEE

The United States National Committee (USNC) was formed by the AIEE in 1906 and was represented that year at the organization meeting of the IEC in London. The AIEE continued to sponsor the USNC and defray its expenses, except for the con-

International Electrical Projects Under IEC Procedure

1. Nomenclature, U. S. National Committee
2. Rating of electrical machinery, British National Committee
3. Symbols, Swiss National Committee
4. Hydraulic turbines, U. S. National Committee
5. Steam turbines, U. S. National Committee
6. Lamp caps and holders, Central Office
7. Aluminum, Central Office
8. Voltages and high-voltage insulators, Italian National Committee
9. Electric-traction equipment, French National Committee
10. Insulating oils, Central Office
11. Rules and regulations for overhead lines, Belgian National Committee
12. Radio communications, Dutch National Committee
13. Measuring instruments, German National Committee
14. Rating of rivers, U. S. National Committee
15. Shellac, British National Committee
16. Terminal markings, Dutch National Committee
17. Oil switches and circuit breakers, Swedish National Committee
19. Internal-combustion engines, U. S. National Committee
20. Electric cables, British National Committee
21. Accumulators, German National Committee
22. Electronic devices (for power applications)
23. Electrical fittings
24. Electrical and magnetic magnitudes and units
25. Letter symbols
26. Electric welding
27. Electro-heating

tributions of money and services by individuals and companies, until 1920, when the desirability of broadening the base for the work became evident. Accordingly, an invitation was extended to, and accepted by, the American Society for Testing Materials (ASTM), the American Society of Mechanical Engineers (ASME), the National Electric Light Association (NELA), and the National Electrical Manufacturers Association (NEMA) to participate in the work. Under these auspices the USNC functioned until 1932 when, on the initiative of the AIEE, an agreement was made with the American Standards Association (ASA) whereby the work was integrated with the broader field of the ASA, and the ASA assumed the administrative expenses of the USNC.

A considerable simplification of the technical organizations responsible for the work of the USNC took place as a result of the consolidation of the USNC work with that of the ASA. The USNC was originally a committee organized solely for IEC purposes, and the ASA had for many years an electrical advisory committee for its purposes. With the reorganization, this electrical advisory committee was reorganized and renamed the electrical standards committee. The membership of this committee consists of 18 representatives of 12 member organizations. The AIEE, the NEMA, and the ASA electric light and power group have three representatives each, and the following organizations have one representative each: American Society for Testing Materials, American Transit Association, Association of American Railroads, ASA communication group, ASA fire protection group, Institute of Radio Engineers, United States Department of Commerce—National Bureau of Standards, United States Navy Department, and United States War Department. The USNC was then set up to be composed of the members of the electrical standards committee, plus three representatives from the American Society of Mechanical Engineers and a group of members-at-large distinguished for their contributions to international standardization work and electrical engineering in general. The chairman of the electrical standards committee since its inception, and in fact since the organization of the old electrical advisory committee, is C. R. Harte (A'10, M'32) of the Connecticut Company, New Haven. Sidney Withington (M'20, F'24) of the New York, New Haven and Hartford Railroad Company is vice-chairman. The president of the USNC is C. H. Sharp (A'02, F'12) who has served in that capacity continuously since the consolidation in 1932 and for many years previous to that time. Other officers are: A. E. Kennelly (A'88, F'13, HM'33) *honorary president;* and C. R. Harte (A'10, M'32) and H. S. Osborne (A'10, F'21) *vice-presidents.* AIEE representatives on the USNC are: V. M. Montsinger (A'14, F'29), H. S. Osborne, and R. E. Hellmund (A'05, F'13); alternates: H. E. Farrer (A'21), E. L. Moreland (A'11, F'21), and E. B. Paxton (A'22, M'25).

The USNC handles the technical work of the 27 IEC projects by assigning the primary responsibility for each to an individual known as technical advisor. The technical advisor secures the broad opinion of American industry through an advisory committee. Prior to the consolidation, the USNC had specially organized groups of advisors for this purpose. Since the consolidation, the sectional committees of the ASA have served as the advisory committees wherever there existed such committees covering the work in question. Regular ASA committees now take care of the work in all but four cases. In the last few years the work of the IEC has been increasing so fast that if some consolidation had not been made much difficulty and confusion inevitably would have resulted. Under the procedure of the ASA, sectional committees are so organized as to contain representation of all branches of the electrical industry having a real interest in the work. In addition, the membership of the committees must be so arranged that neither the producers nor consumers have a majority of the members.

In all this work, the AIEE is continuing to play the vital part which it has since the inception of the work of the IEC. The Institute has an ideal setup for conducting the underlying discussions and research work necessary for the development of new standards and for revising old standards to bring them in line with the ever-changing conditions of present-day industry. The material thus developed, when fed into the regularly organized machinery of the ASA and, where desirable, on to the IEC, constitutes the basis for American Standards and the American point of view on international standards.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and the other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Electricity for Treasure Island

To the Editor:

I note that in the article entitled "Electricity for Treasure Island" in the April issue of ELECTRICAL ENGINEERING, contrast is drawn in several places on pages 150 and 151, between "fluorescent" lamps and "Mazda" lamps. This is an unfortunate error; the term "Mazda" is applied by the manufacturers to both fluorescent and incandescent lamps.

Very truly yours,

W. S. H. HAMILTON (A'19, M'26)

(Chairman, AIEE Committee on Transportation; Equipment Electrical Engineer, New York Central System, New York, N. Y.)

The Student Engineer and "Electrical Engineering"

To the Editor:

I wish to amplify the importance and utility of the student engineer and his place in the engineering journal as brought to light so nobly by Doctor Sorensen (*EE, April '39, p. 181–82*). If we were to glance over the other national engineering society publications, we would readily feel that we were acting in a negative direction as far as student activities are concerned. If we were to retrocess the past several months we would find numerous data in ELECTRICAL ENGINEERING which has for its main theme "the student engineer." The student in these articles was inoculated with much ingenious material of a valuable future nature. This material was given much care and detailed thought as pointed out in the symposium dealing with "Co-ordination of Physics With Electrical Engineering," "Graduate Training for Engineers," "Training Engineering Graduates in Industry," and many others. All the articles were either written by engineers in industry, or by engineering educators, aimed directly at the student. The student then becomes similar to the defendant before the judge in which he has little or nothing to say. We could offer remedially in the case of the student the "Sorensen Method" or the student page. As matters stand at present we do not have a perfect equilibrium because the student does not have any medium in which to express his viewpoints, the viewpoints being along the lines of student training, graduate courses, engineering and mathematics, and many others.

In relation to student graduate courses most men feel that after they have put in four years of time, energy, and money in an engineering course, they are desirous to go in the field and apply their potential abilities. The average student after four years in college finds his interest at a minimum and has no desire to continue his course immediately. My observation has been that some students have in mind at the time of graduation the intent of going back to school, either night or day, after one or two years in industry. At the time of graduation a very small percentage of the students have any definite specialization in mind. Those that have some definite thing in mind do not continue due to the lack of money, or because they feel that the school does not have ample facilities, to take care of their desires. Men in my class felt that specialization could be obtained more efficiently in industry.

In the co-ordination of mathematics and

physics with engineering, most students felt that their knowledge of mathematics although they covered a two year period was insufficient to analyze and derive a large percentage of problems. This was especially true when the calculus had to be used whereby it acted as a medium in solving problems. The general attitude of calculus as a tool in solving problems seems universal in most colleges in that the student dodges it as much as he possibly can. The reason in my opinion that a student and even practicing engineers avoid calculus as much as possible is due to their poor understanding of the subject. Most men in my class felt that insufficient time was devoted to physics, and that physics that involved an understanding of the higher mathematics was taught before the mathematics was taught. We all agreed, including the instructor, that if more time was spent on the fundamentals of physics less time in the future would have to be spent on electrical engineering.

These are a few of the reactions of a class of electrical engineers to some of the phases of the art and science. If the student page were made part of the engineering journal much more detail could be analyzed by individual students, which would prove advantageous to instructor, industry, and student alike.

Yours very truly,

HERBERT JAY COBBS (A'39)

(Jamaica, N. Y.)

Engineering Education

To the Editor:

Of course every engineer is loyal to his *Alma Mater*—the best college in the world, with the best faculty, the best professors and teachers, the best alumni, and the best students. *Rah! Rah! Rah!* Now that we have that out of our systems suppose we, who are accustomed to deal with facts, prepare a little questionnaire to be submitted to the faculties of all the colleges except the one we honored by permitting it to engrave our names on some of its sheepskins:

1a. What proportion of your teaching force was receiving a salary of $5,000 or over from some industrial organization, when you invited them to assist in preparing your young men to become engineers?

1b. $2,500 to $5,000?

2. What proportion of your 1938 graduates were more healthy than when they entered college, because of habits of exercise, study, rest, and diet you trained them to follow?

3a. What proportion of your 1938 graduates were placed by your efforts in positions in keeping with the technical course you gave them?

3b. What was the average starting wage?

4. Do you train ALL your graduates by forums, debates, etc., to know how to talk intelligently and convincingly on matters of concern to all citizens of the United States? (This would give them ability to express their ideas on engineering matters as well.)

There probably was a time when our colleges, to meet expenses, had to accept almost any boy left by devoted, self-sacrificing parents at the college gate. Now, however, the number of applicants has so increased that the colleges in self-defense can select by rigid examination those whose qualifications make them the most promising. The colleges cannot be blamed for the raw material turned over to them for polishing; rather they are to be commended for the results they do achieve with many unpromising specimens.

In economics the law of supply and demand is often referred to, but in educational institutions the supply of students appears unlimited and the demand for graduates often seems nonexistent. As in the case of wheat and cotton, pork and beef, the trouble is underconsumption, and we must as a people learn to utilize more intelligently the thousands of young men who have received an engineering education.

When these young engineers emerge with their sheepskins, they are of such an age that their chief aim in life is to have a home of their own. It would seem hardly more than fair that after four years of preparation, they should be assured a modest salary which would enable them to be normal, useful, self-supporting citizens. After working faithfully for four years and completing a course of training prescribed by those who are paid to know how to prepare men for an engineering career, it is stark tragedy for a graduate to learn that his diploma is chiefly an expensive ornament. The college which accepts tuition, should guarantee a technical job of some kind at not less than $30 a week to each graduate or so modify its courses of training that it will be able to do so.

Until colleges perfect their four year courses of training for the engineering profession, it is obviously futile to consider postgraduate work for, with properly arranged four-year courses, postgraduate work should be unnecessary.

Colleges should be developing not merely technicians, but useful citizens whose trained habits of thought and reasoning should enable them to lead the nation in its crusade "to establish justice, insure domestic tranquility, and promote the general welfare of all the people of the United States."

Very truly yours,

WM. B. TAYLOR (A'05, M'16)

(Plympton, Mass.)

A Modified Slip Test for Measuring Synchronous Reactance

To the Editor:

It has been my experience that the slip test originally proposed by Haga[1] for determining the direct and quadrature synchronous reactances[2] of salient-pole machines quite frequently gives unsatisfactory results when performed in the usually prescribed way for power laboratory experiments. Several disturbing factors are those introduced by hunting due to slip-pulsation of magnetic reluctance; tendency of the generator under test to pull into step and run as a synchronous machine; and errors introduced in reading extreme deflections of ammeter (and voltmeter) needle when correct conditions are finally obtained.

In power laboratories where the equipment is available, a slightly different test can be made which would seem to be more reliable and certainly more instructive to students interpreting the data for the first time. The set used in our laboratories was a three-machine set consisting of a d-c motor coupled directly to two 15-kva salient-six-pole a-c generators, one of which has a rotatable stator resulting from its electrodynamometer construction. With machines wye-connected, the output of the fixed-stator machine was fed to the movable-stator unit and field adjustment made for approximately rated current of 40 amperes. Obviously this arrangement gives complete synchronism between the rotating field on the stator and the field structure of the machine under test. By rotating the stator through some 180 electrical degrees, the entire periodic variation of synchronous reactance could be observed from the readings of ammeter and voltmeter, while for any fixed position of the stator, readings were entirely steady.

The results showed a quadrature-axis reactance of 2.3 ohms per wye phase, and a direct-axis reactance of 3.6 ohms, the latter value being identical with the usual synchronous reactance determined from short-circuit data and the air-gap line for the magnetic circuit of the machine.

It might be mentioned that this test could also be performed with a two-machine set if the driving unit were a synchronous motor. However, in this case some means might have to be available for controlling the alternating voltage impressed on the generator under test.

REFERENCES

1. Haga, Lumière électrique, 7, Series 2, 329, 1909.

2. THE REACTANCES OF SYNCHRONOUS MACHINES, R. H. Park and B. L. Robertson. AIEE TRANSACTIONS, volume 47, 1928, pages 514–35.

Yours very truly,

HENRY B. HANSTEIN (A'26)

(Instructor in electrical engineering, College of the City of New York, N. Y.)

Tensors and Electrical Networks

To the Editor:

As I noted in a letter published in the January 1938 issue of ELECTRICAL ENGINEERING, a widespread misconception has been created as to what tensors will do in the theory of electrical networks. As pointed out, Professor Struik, in a set lecture before the American Mathematical Society, said that tensor analysis as used by Kron enabled one to transform one network into another. The quotation to the same effect in the present discussion is from Kron's new book on tensors ("Tensor Analysis of Networks," Gabriel Kron, John Wiley and Sons, Inc., New York, 1939). Professor Synge, who has addressed the AIEE (1935 Summer convention. Ithaca, N. Y.) and the American Mathematical Society (last St. Louis meeting) on tensors and the application of tensor analysis to electrical-network theory, has written me to the effect that he has understood that this type of transformation was possible. Statements to the same effect have

been made publicly before the Society for the Promotion of Engineering Education.

In the analysis which follows I examine this claim critically and find it to be almost baseless. For the sake of clarity, I have taken the simplest possible network but the argument can be generalized to networks of any complexity.

In vector analysis, a tensor means a linear vector operator or dyadic giving a collineation or affine transformation. In tensor analysis the tensor is defined more broadly by a law of transformation with respect to the totality of co-ordinate systems of the linear group. The older viewpoint of vector analysis was implicit in my original note "On the Impedance as a Tensor" (*Philosophical Magazine*, June 1924, page 1094), in the later papers of Kron and Sah on dyadics, and in the fundamental monographs by Cauer, Quade, and Burington on matrices. The newer viewpoint is desirable in certain branches of geometry, certain geometrical interpretations of dynamics, and is necessary in the theory of relativity, but in the theory of electrical networks it is not necessary nor, as will be proved, generally applicable.

Let $I_1, I_2, \ldots$ be the currents in the branches of an electric network, say the network having the delta connection represented in figure 1, and consider the transformation

$$\left.\begin{aligned} I_1 &= I_1' + I_2' + I_3' \\ I_2 &= \quad I_2' + I_3' \\ I_3 &= \quad\quad I_3' \end{aligned}\right\} \qquad (1)$$

selected at random. As all admissable co-ordinate systems are on a parity in the tensor viewpoint, the primed currents must be branch currents: implying figure 2. But

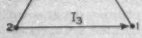


Figure 1

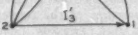


Figure 2

by Kirchhoff's condition at the junctions, as ordinarily understood, the nullity of figure 2 is different from that of figure 1. Hence figure 2 is ruled out and the primed variables cannot have the same physical interpretation as the unprimed. Only the latter are true branch currents and the former are merely linear combinations of them having no proper graphical nor physical interpretation. Hence the graph of the new variables, if there is one, must be figure 3.

But the admissibility of figure 3 is not secure. Consider the Kirchhoff constraints $NI = 0$ for figure 1, where

$$N = \begin{vmatrix} 0 & 1 & -1 \\ 1 & 0 & 1 \\ -1 & -1 & 0 \end{vmatrix} \qquad I = \begin{vmatrix} I_1 \\ I_2 \\ I_3 \end{vmatrix}$$

Under the transformation (1) they become $NAI' = 0$ where

$$A = \begin{vmatrix} 1 & 1 & 1 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{vmatrix} \qquad NA = \begin{vmatrix} 0 & 1 & 0 \\ 1 & 1 & 2 \\ -1 & -1 & -2 \end{vmatrix}$$

From the tensor principle of parity of co-ordinate systems NA implies figure 4 in the same way that N implies figure 1. But figure 4 is in disagreement with figure 3 and the two figures are reconcilable only when $I_1 = I_2 = I_3 = 0$.

We may describe this situation by saying that the branch currents form an absolute reference system. The only admissible

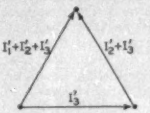


Figure 3

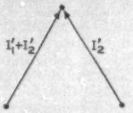


Figure 4

transformation of them in the tensor sense is the identity.

There is also evidence that the junction points form an absolute reference system in a similar way from the fact that most transformations on them lead to meaningless corresponding graphs; for example, the derived incidence matrix given by Professor Tucker in ELECTRICAL ENGINEERING, May 1937, page 620, has no graphical or physical interpretation.

It has been claimed recently that "it is possible to establish a non-singular transformation matrix between any two n-coil networks, no matter how many meshes, junction pairs, and sub-networks each one has." As this result is in conflict with the findings here given if the transformation is on the branch currents, and in conflict with dynamics if on the loop currents, a critical examination of this much-heralded result of the tensor viewpoint becomes necessary.

Consider the problem of finding the transformation which will carry the series connection of figure 5 over into the parallel

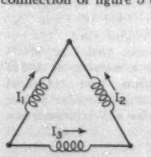


Figure 5

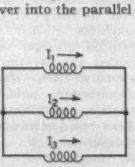


Figure 6

connection of figure 6. Our procedure may be as follows:

First, introduce the loop-currents proper i_1', i_1'', i_2''.

Second, extend the graphs to figures 7, 8, respectively.

Third, introduce the loop currents i_2', i_3', i_3'' as required by the nullity of the new figures.

Fourth, write down the relation between the branch currents and the loop currents for the respective cases:

$$\begin{vmatrix} I_1 \\ I_2 \\ I_3 \end{vmatrix} = \begin{vmatrix} 1 & 1 & 0 \\ -1 & 0 & 0 \\ -1 & 0 & 1 \end{vmatrix} \begin{vmatrix} i_1' \\ i_2'' \\ i_3'' \end{vmatrix},$$

$$\begin{vmatrix} I_1 \\ I_2 \\ I_3 \end{vmatrix} = \begin{vmatrix} 1 & 0 & 1 \\ -1 & 1 & 0 \\ 0 & -1 & 0 \end{vmatrix} \begin{vmatrix} i_1' \\ i_2' \\ i_3' \end{vmatrix}$$

These equations may be written

$$I' = C_1 i' \qquad I'' = C_2 i''$$

where the primes and double primes distinguish the columnar matrices in the two cases.

Figure 7

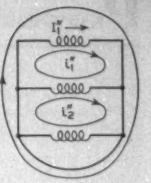


Figure 8

Since C_1, C_2 represent, in an obvious way, the *graphs* of figures 7 and 8, respectively, and since we can write

$$C_2 = (C_2 C_1^{-1}) C_1 \qquad (2)$$

$$C_1 = C_1 (C_1^{-1} C_2) \qquad (3)$$

we have

graph 2 = operation on graph 1

The operators in cases (2) and (3) are, respectively

$$C_a = \begin{vmatrix} 0 & -2 & 1 \\ 1 & 2 & 0 \\ -1 & -1 & 0 \end{vmatrix} \qquad C_b = \begin{vmatrix} 1 & -1 & 0 \\ 0 & 1 & 1 \\ 1 & -2 & 0 \end{vmatrix}$$

We next remark that the matrix equation $I' = C_a I''$ is a consequence of writing $i' = i''$ $i' = C_b i''$ is a consequence of writing $I' = I''$

so that C_b, as the matrix of the transformation on the generalized currents, carries the network of the impedance matrix Z over into $\bar{Z} = C_b^T Z C_b$, where

$$Z = \begin{vmatrix} z_1 + z_2 + z_3 & z_1 & -z_3 \\ z_1 & z_1 & 0 \\ -z_3 & 0 & z_3 \end{vmatrix},$$

$$\bar{Z} = \begin{vmatrix} z_1 + z_3 & -z_3 & z_1 \\ -z_3 & z_2 + z_3 & 0 \\ z_1 & 0 & z_1 \end{vmatrix}$$

The following points may now be made:

1. No external electromotive forces will encounter the same impedance in the new network that it did in the old.

2. The network of figure 5 has not been carried over to that of figure 6 since the equations $i_3' = i_3'' = 0$ do not hold.

3. All impedance branches are *permanently short-circuited!*

This C_b, which applies only to networks with short-circuited impedance branches and gives only networks with short-circuited impedance branches, is Kron's C' ("Tensor Analysis of Networks," pages 418–33, page 152, etc.). The presence of externally impressed currents and electromotive forces and complexity in the network do not alter the true situation but may, of course, conceal it.

Tensor analysis has legitimate though academic application in a determination of network properties invariant with respect to the choice of sets of independent loop currents, but when this analysis has once been made for the general case the application ceases.

Yours truly,

W. H. INGRAM

(New York, N. Y.; Member, American Mathematical Society)

Personal Items

H. B. Dates (A'98, F'32) will retire as head of the department of electrical engineering at Case School of Applied Science, Cleveland, Ohio, July 1, 1939, with the title of professor emeritus. Born in New Britain, Conn., July 15, 1869, he received the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1894, and the honorary degree of electrical engineer from Case School in 1908. For two years after graduation he was employed by Westinghouse Electric and Manufacturing Company at Newark, N. J., and East Pittsburgh, Pa., before becoming professor of physics and electrical engineering at the newly established Clarkson School of Technology, Potsdam, N. Y., where he remained until 1903. For the two following years he was professor of electrical engineering and dean of the engineering school of the University of Colorado, Boulder, and in 1905 he became head of the Case School electrical-engineering department, where he has continued ever since. He has also carried on a consulting practice in electrical engineering, and has been a consultant for the Cleveland Board of Education and others on school lighting. He is a member of the AIEE committee on the production and application of light, and was the first chairman (1907–08) of the Cleveland Section. He is a past-president of the Illuminating Engineering Society, a member of the International Commission on Illumination, the National Electric Light Association, the Society for Promotion of Engineering Education, and Sigma Xi, and the author of many technical articles.

H. E. Dexter (A'14, M'17) has been appointed vice-president in charge of commercial relations by the Central Hudson Gas and Electric Corporation, Poughkeepsie, N. Y. Born at Randolph, Mass., in 1890, he received the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1912, and entered the testing department of the General Electric Company, Schenectady, N. Y., the same year. He continued with that company until 1917, when he entered the United States Army, serving as a lieutenant in the engineering service. After the war he went to Shanghai, China, as engineering sales representative of Anderson, Meyer, and Company, continuing as manager of the Foochow office of Anderson, Meyer, and Company, Ltd. Returning to the United States, he became refrigeration engineer, and then president of the Ideal Heating Company, Kansas City, Mo. For a time he was chief of the electrical equipment division, United States Bureau of Foreign and Domestic Commerce, Washington, D. C. He was first employed by the Central Hudson corporation as assistant commercial manager, becoming general commercial manager, and later, in 1935, a director of the company. He is chairman of the general sales committee of the Edison Electric Institute.

M. W. Smith (A'20, M'36) manager of engineering of the Westinghouse Electric and Manufacturing Company, with headquarters in Pittsburgh, Pa., has been elected a vice-president of the company. He will direct all engineering activities. A native (1893) of Overton, Tex., Mr. Smith graduated from Texas Agricultural and Mechanical College in 1915 with the degree of bachelor of science in electrical engineering. He then entered the student apprentice course at the Westinghouse company's East Pittsburgh works, and has remained with the company continuously ever since. He has been associated with generating engineering operations, first as a design engineer, then a section engineer (1926), then division engineer in charge of the design of large a-c machines (1930). In 1936 he was appointed manager of engineering. He received the Westinghouse Order of Merit award in 1938. He is a member of AIEE membership, publication, and technical program committees, and a member of the American Association for the Advancement of Science.

J. W. Latham (A'27) has been appointed chief engineer of the Chesapeake and Potomac Telephone Company of Baltimore City, Md. A native (1886) of Hickory Grove, Va., Mr. Latham is a graduate of the University of Virginia. He was employed in the engineering and installation departments of the Western Electric Company, Chicago, Ill., in 1906, and transferred the following year to the engineering department of the Chicago Telephone Company. He became an engineering inspector for the Southern Bell Telephone and Telegraph Company, Atlanta, Ga., in 1909 continuing with that company as division traffic supervisor, first in Charlotte, N. C., then in Savannah, Ga.; traffic equipment engineer, Atlanta, exchange traffic and operating practice engineer, Atlanta. In 1920 he entered the engineering department of the Chesapeake and Potomac Telephone Company, Washington, D. C., and shortly afterward was appointed facilities engineer. He later became chief engineer for the Chesapeake and Potomac Telephone Company of West Virginia, and held that position until his recent appointment.

M. M. Kenneally (A'29) has been appointed vice-president in charge of sales of the Porcelain Insulator Corporation, Lima, N. Y. A native (1894) of Oelwein, Iowa, Mr. Kenneally received the degrees of bachelor of science in electrical engineering, 1915, and electrical engineer, 1920, from Iowa State College. During the World War he was an engineering officer in the United States Navy. In 1919 he became distribution survey engineer for the Waukesha (Wis.) Gas and Electric Company, and during the next eight years was employed in various engineering and executive capacities by the Citizens Gas and Electric Company, Waterloo, Iowa; the Philadelphia Suburban Gas and Electric Company, Jenkintown, Pa.; the Iowa Public Service Company, Humboldt; and the United Gas Improvement Company, Philadelphia, Pa., and on distribution surveys for the cities of Belleville and Kewanee, Ill. In 1927 he was employed by the Ohio Insulator Company, Barberton, and in 1928 became sales manager of the New York office of the Ohio Brass Company. Three years later he was transferred to Mansfield, Ohio, as sales manager of the power utilities department of that company. He became sales manager of the Porcelain Insulator Corporation in 1937.

F. B. Jewett (A'03, F'12) vice-president of the American Telephone and Telegraph Company and president of Bell Telephone Laboratories, Inc., New York, N. Y. has been elected president of the National Academy of Sciences. He was also honored recently for his scientific attainments by the

M. M. KENNEALLY H. E. DEXTER M. W. SMITH J. W. LATHAM F. B. JEWETT

A. C. STREAMER B. K. BOYCE J. R. READ R. H. HUGHES R. B. MAC GUINNESS

presentation of the 1939 John Fritz Medal. An article outlining his qualifications for that award appeared in the March 1939 issue (pages 115–17), and a biographical sketch in the December 1938 issue (page 521).

W. R. G. Baker (A'19) has been appointed manager of the General Electric Company's newly organized radio and television department, with headquarters at Bridgeport, Conn. The new unit will co-ordinate all radio, television, and related activities. Doctor Baker has been engaged in radio development work since 1917. A native (1891) of Lockport, N. Y., he attended Union College, from which he holds the degrees of bachelor of engineering, master of electrical engineering, and doctor of science. Before entering the General Electric laboratories in 1917 he was employed by the New York Telephone Company. In 1924 he was placed in charge of design of all radio products for General Electric, and in 1926 he was given complete charge of radio development, design, and production. On formation of the RCA-Victor Corporation in 1929 he was made head of radio engineering activities, and later general manager of the plant at Camden, N. J. He resumed his connection with General Electric in 1936, becoming managing engineer of the radio receiver section at Bridgeport. Before his recent appointment he was chairman of the radio management committee.

J. R. Carson (A'19, F'33) research mathematician, Bell Telephone Laboratories, Inc., New York, N. Y., has been awarded the Elliott Cresson Medal by the Franklin Institute, Philadelphia, Pa., "in consideration of outstanding contributions to the art of electrical communication." A native (1887) of Pittsburgh, Pa., Mr. Carson received the degrees of bachelor of science (1907) electrical engineer (1909), and master of science (1912) from Princeton University. He was an instructor in physics and electrical engineering at Princeton University, Princeton, N. J., from 1912 to 1914, when he was employed in the engineering department of the American Telephone and Telegraph Company. He was transferred to the department of development and research in 1917, with the title of transmission theory engineer, and assumed his present position in the Bell Laboratories in 1934. He received in 1924 the Liebmann Memorial Prize of the Institute of Radio Engineers, of which he is a member. He is also a member of the American Mathematical Society and Phi Beta Kappa, and has written books and articles on technical subjects.

B. K. Boyce (A'10, M'28) has been appointed chief engineer, Manhattan area, by the New York Telephone Company. A native (1886) of Little Valley, N. Y., Mr. Boyce graduated in electrical engineering at Cornell University in 1907, and has been with the New York Telephone Company ever since. He was engaged in special studies on electrolysis, inductive disturbances, and protection, from 1907 to 1912, and on transmission work, including design, 1912–24. During the next two years he did plant extension work, becoming transmission and plant extension engineer in 1925. In 1926 he was appointed chief engineer for the upstate New York area, and continued in that position until his present appointment. He was a member of the AIEE committee on communication 1930–31.

J. R. Read (A'04) has been elected president of Canadian Westinghouse Company, Ltd., Hamilton, Ont., Canada. Born in Virginia October 24, 1879, Mr. Read began his electrical engineering experience with the Sterling White Lead Company, Parnassus, Pa., afterward spending three years as a student engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He was employed as engineer by the Cherokee Gold Dredging Company, and the Northern California Power Company before entering the employ of Canadian Westinghouse in 1904 as sales engineer for the Vancouver district office. He was appointed district manager of the Vancouver district in 1908, was made a vice-president in 1936, and a director of the company in 1938.

R. H. Hughes (A'20, M'30) has been appointed vice-president and general manager of the Bronx-Westchester area of the New York (N. Y.) Telephone Company. He had been an assistant vice-president since 1927. A native (1891) of Decatur, Ala., Mr. Hughes graduated from Vanderbilt University in 1913, with the degree of bachelor of engineering. He has been with the New York Telephone Company continuously since 1914, when he entered the engineering department. He became a local trunk engineer in 1925, and plant extension engineer in 1927.

A. C. Streamer (A'10) has been appointed general manager of the East Pittsburgh division of the Westinghouse Electric and Manufacturing Company. He was formerly manager of the switchgear division of the East Pittsburgh works of the company. After graduating from the University of Colorado in 1907 with the degree of bachelor of science in electrical engineering, Mr. Streamer entered the apprentice engineering course of the Westinghouse company at East Pittsburgh, and was later assigned to the switchboard engineering division. He was made manager of the diversified products department in 1931, and manager of the switchgear division on its formation in 1936.

R. B. MacGuinness (A'09) has been appointed vice-president in charge of operations by the Central Hudson Gas and Electric Corporation, Poughkeepsie, N. Y. A native (1883) of New York, N. Y., Mr. MacGuinness was employed in various capacities by the Westchester Light Company from 1901 to 1908, when he was placed in charge of the electrical department of Russell Birdsall and Ward Bolt and Nut Company, Port Chester, N. Y. He continued with that organization until his employment by the Central Hudson corporation in 1923 as division superintendent. He has been operating manager since 1926 and a director since 1932.

G. H. Bucher (M'24) president, Westinghouse Electric and Manufacturing Company and Westinghouse Electric International Company, was awarded the Westinghouse Order of Merit in 1938. A native (1888) of Sunbury, Pa., Mr. Bucher attended Pratt Institute and became associated with the Westinghouse company as a student engineer in 1909. The Order of Merit, founded in 1935, is awarded Westinghouse employees for outstanding contributions to the electrical and mechanical arts and to company progress. Other AIEE members to receive the award in 1938 are: **M. W. Smith** (A'20, M'36), recently appointed vice-president in charge of engineering, Pittsburgh, Pa.; **G. W. Penney** (A'26), manager,

electrophysics division, research laboratories; **C. M. Laffoon** (A'24) manager, a-c generator engineering department; **J. B. MacNeill** (A'18, M'36) manager, switchgear engineering; **D. F. Miner** (M'34) manager, engineering laboratories and standards; **J. S. Parsons** (A'27) central station engineer; **F. B. Powers** (M'37) engineering manager, transportation department; **I. B. Stiefel** (A'18) manager of industrial relations; all at East Pittsburgh, Pa.; **J. K. Hodnette** (A'25, M'30) transformer development engineer, Sharon, Pa.; **A. W. Copley** (A'04, F'26) engineering manager, Pacific Coast district, San Francisco, Calif.

Barry Dibble (A'06, M'12) has been appointed assistant administrator of the Bonneville Dam project, Portland, Ore. He was formerly a consulting electrical engineer for the United States Indian Service. A native (1881) of St. Paul, Minn., Mr. Dibble graduated in electrical engineering from the University of Minnesota in 1903. He was employed in engineering capacities by the Jackson and Battle Creek Traction Company, Albion, Mich., the Cincinnati and Columbus Traction Company, Cincinnati, Ohio, the Shawinigan Water and Power Company, Shawinigan Falls, Quebec, Can., and the Twin City Rapid Transit Company, St. Paul, Minn., before entering the service of the United States Government as an electrical engineer in the Reclamation Service. He was a construction engineer and later project manager of the Minidoka (Idaho) project, and later had headquarters in Denver, Colo. For more than ten years he has been in consulting practice, with offices at Redlands, Calif.

P. L. Hoover (A'24) has been appointed professor of electrical engineering and head of the electrical engineering department of Case School of Applied Science, Cleveland, Ohio. A native (1898) of Mansfield, Ohio, Doctor Hoover received the degree of bachelor of science at Carnegie Institute of Technology, and the degrees of master of science and doctor of science from Harvard University, where he was for three years a research fellow in electrical engineering. He has also studied at the Universities of Vienna and Paris. He was appointed associate professor of electrical engineering at Case School in 1927, continuing in this position until 1930, when he became assistant director of the engineering experiment station at Rutgers University, New Brunswick, N. J. In 1934 he was made director of the station with the rank of professor. He is a member of the American Physical Society, the American Association for the Advancement of Science, Sigma Xi, Gamma Alpha, and Tau Beta Pi, and is the author of various technical articles.

J. S. Jones (A'19, F'25) has been made manager of the western division, American Machine and Metals, Inc., San Francisco, Calif. A native (1888) of Norfolk, Va., Mr. Jones attended the Naval Apprentice School at the Norfolk Navy Yard, where he was afterward employed from 1909 to 1911. In 1911 he became an electrical draftsman at the Navy Yard, New York, N. Y., where he advanced through successive positions to that of senior electrical aide and acting electrical superintendent of the Third Naval District in 1918. In 1919 he went with Charles Cory and Son, Inc., New York, as assistant to the vice-president and engineer, and in 1923 became vice-president, general manager, and director of engineering of that company. Later he became assistant to the president, Consolidated Laundries Corporation, New York, then vice-president of American Machine and Metals, Inc., Washington, D. C. He left that organization to become vice-president of Stewart and McGuire, Inc., New York, for two years before returning to assume his present position.

J. B. HARRIS, JR.

J. B. Harris, Jr. (A'17) has been appointed vice-president of the Rumsey Electric Company, Philadelphia, Pa. A biographical sketch of Mr. Harris appeared in the May issue (page 228).

G. A. Sawin (A'03, M'13) has been appointed director of the regulatory legislation department of the National Electrical Manufacturers Association, with headquarters in New York, N. Y. He was formerly assistant manager, central station sales, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and an associate representative of the Westinghouse company on the electrical instrument and transformer sections and the rural electrification publicity subcommittee of the NEMA. A graduate (1901) in electrical engineering at Harvard University, Mr. Sawin was employed by the General Electric Company, Lynn, Mass., and the Public Service Electric Company, Newark, N. J., before his association with the Westinghouse company.

C. T. Hughes (A'20, M'29) has been appointed general operating superintendent of the Connecticut Light and Power Company, Hartford. Born (1894) in Wickliffe, Ky., Mr. Hughes graduated from the University of Oklahoma in 1918 with the degree of bachelor of science in electrical engineering. He spent several months in the Signal Corps of the United States Army, and in December 1918 was employed by the Connecticut Light and Power Company as an assistant electrical engineer. He has been with the company continuously since that time, as electrical engineer and design engineer, and until his recent appointment, general engineer, with headquarters at Waterbury, Conn.

M. G. Lloyd (A'08, F'12) chief of the section of safety codes of the National Bureau of Standards, Washington, D. C., has been elected president of the International Association of Electrical Inspectors. Doctor Lloyd, who holds the degrees of bachelor of science (1896), doctor of philosophy (1900), and electrical engineer (1908), from the University of Pennsylvania, has occupied his present position with the Bureau of Standards since 1917. He is a member of the AIEE committees on safety and protective devices, and past chairman of the Washington Section. He is president of the Washington (D. C.) Safety Society and member of a number of other technical organizations.

Roy Martindale (M'21) has been appointed electrical engineer in charge of operations for the Bureau of Power and Light of the City of Los Angeles, Calif. A native (1884) of Attica, Ind., he received the degree of bachelor of science in electrical engineering from Purdue University in 1906, and during the following year was a student engineer for General Electric Company, Schenectady, N. Y. From 1908 to 1911 he was employed on power projects by the Washington Water Power Company, Spokane, Wash. He has been with the Los Angeles Bureau of Power and Light since 1911, assuming in 1920 the position of assistant operating engineer which he held until his recent appointment.

C. W. Green (A'10, M'26) has been appointed technical representative in Europe for the Bell Telephone Laboratories, Inc. Born in 1884 in Waukegan, Ill., Mr. Green graduated in 1907 from the University of Wisconsin, with the degree of bachelor of science. He was an instructor in electrical engineering at Massachusetts Institute of Technology, Cambridge, from 1907 to 1914 and assistant professor, 1914–17. During the World War he served in the United States Coast Artillery, attaining the rank of major. He became a telephone engineer for Western Electric Company, New York, N. Y., in 1919, and transferred to the Bell Laboratories in 1924.

L. F. Pries (A'33) with two partners, has organized Central States Industrial Engineers, DeKalb, Ill., designers and builders specializing in production machinery for the wire industry. A native (1907) of Buffalo, N. Y., Mr. Pries received the degrees of electrical engineer, 1931, and master of electrical engineering, 1932, from Rensselaer Polytechnic Institute. After graduation he was employed by the Colonial Radio Corporation, Buffalo, as a development engineer by the Wurlitzer Grand Piano Company, DeKalb, Ill., and in the engineering department of the DeKalb plant of the American Steel and Wire Company.

H. R. Peddicord (A'38) has been appointed general buildings and supplies superin-

tendent, Chesapeake and Potomac Telephone Company, Washington, D. C. A native (1900) of Cooksville, Md., Mr. Peddicord received the degree of bachelor of science in electrical engineering from the University of Maryland in 1921. He spent a year in the student course of the Westinghouse Electric and Manufacturing Company East Pittsburgh, Pa., and a year teaching mathematics in New York, N. Y. Since 1923 he has been with the Chesapeake and Potomac company. From 1936 until the present he had the position of engineer.

R. L. Horr (M'26) has been appointed general plant engineer by the Mountain States Telephone and Telegraph Company, Denver, Colo. Mr. Horr is an electrical engineering graduate of the University of Illinois (1904), and was employed in maintenance and inspection work by the Chicago (Ill.) Telephone Company 1904–14. During the next two years he was chief engineer for the Montana Fruit and Irrigation Company, after which he spent four years in business. He has been with the Mountain States company since 1920, and before his present appointment was general plant supervisor.

R. C. Muir (A'08, M'19) vice-president in charge of engineering, General Electric Company, Schenectady, N. Y., will be awarded the honorary degree of doctor of engineering by the University of Wisconsin at its 1939 commencement exercises. Mr. Muir is a graduate of the University of Wisconsin, having received the degree of bachelor of science in electrical engineering in 1905. He entered the General Electric student engineering course at Schenectady the same year, and has been with the company ever since, assuming his present position in 1934.

R. P. Long (A'34) has been appointed general plant employment supervisor, eastern district, Bell Telephone Company of Pennsylvania, Philadelphia, Pa. After graduating in electrical engineering from Cornell University in 1921, Mr. Long entered the employ of that company, later becoming plant transmission engineer. Before his recent appointment he was district plant superintendent.

J. E. M. Mitchell (A'27) has been appointed assistant sales manager of Porcelain Products, Inc., Parkersburg, W. Va. He was formerly general sales manager, Jeffery-DeWitt Insulator Company, Kenova, W. Va., having been associated with that company since 1924, and prior to that was a sales engineer with W. K. Beaven, Birmingham, Ala.

G. R. Mezger (A'37) has been appointed assistant sales manager on industrial sales of television equipment by the Allen D. DuMont Laboratories, Inc., Passaic, N. J. A graduate in electrical engineering of Rensselaer Polytechnic Institute, Mr. Mezger has been a research and development engineer for the DuMont Laboratories since 1936.

A. E. Kennelly (A'88, F'13, HM'33) has been elected a member of the Royal Academy of Sciences of Upsala, Sweden. Doctor Kennelly is professor emeritus of electrical engineering at Harvard University and Massachusetts Institute of Technology, and AIEE past-president and Edison Medalist (1933). A biographical sketch of him appeared in the October 1938 issue (page 433).

E. E. Wyland (A'29) has been appointed general plant supervisor, Mountain States Telephone and Telegraph Company, Denver Colo. A graduate of the University of Idaho, Mr. Wyland has been with the company since 1924, much of the time in the transmission department. Before his present appointment he was acting Idaho plant superintendent.

P. A. Condit (A'37) has been employed as a control engineer by the Cooper-Bessemer Corporation, Mount Vernon, Ohio. He was formerly in charge of development and field engineering for the Mason-Neilan Regulator Company, Boston, Mass.

R. H. Manahan (M'22) chief, electrical division, Department of Building and Safety, City of Los Angeles, Calif., has been appointed chairman of the legislative committee, southwestern district, International Association of Electrical Inspectors.

E. S. McConnell (A'29, M'36) formerly electrical engineer for Anaconda Wire and Cable Company, New York, N. Y., is now with the Copper Wire Engineering Association, Washington, D. C., as electrical engineer.

R. O. Froling (A'37) has been employed as an engineer in the vibration department of the propeller division of the Curtiss Wright Corporation, Clifton, N. J. He was formerly a student engineer with the General Electric Company, at Pittsfield, Mass.

O. G. Owens (A'38) has been appointed an instructor in the university extension division, Rutgers University, New Brunswick, N. J. He was formerly a student physicist at General Electric Company, Lynn, Mass.

R. S. Brannin, Jr. (A'37) formerly a logging operator for the Humble Oil and Refining Company, Houston, Tex., has been employed by the Lago Petroleum Corporation, Maracaibo, Venezuela.

W. F. Sims (A'20, F'33) chief electrical engineer, Commonwealth Edison Company, Chicago, Ill., has been elected a director of the Electric Association of Chicago, to complete the 1939–40 term.

H. V. Dobson (A'28) city electrician, City of Santa Barbara, Calif., has been appointed chairman of the articles of association committee, southwestern district, International Association of Electrical Inspectors.

A. R. Small (M'37) president, Underwriters Laboratories, Chicago, Ill., was elected a vice-president of the National Fire Protection Association at its recent annual meeting.

C. C. Curtis (M'23) president, Savannah Electric and Power Company, was elected third vice-president of the Southeastern Electric Exchange at its recent annual convention at St. Augustine, Fla.

A. D. Bragg (A'36), sales representative, General Electric Company, Fresno, Calif., has been elected president of the Engineers Club of Fresno.

P. A. Ward (A'37) field engineer, air conditioning department, General Electric Company, has been transferred from Chicago to the Detroit office of the department.

L. L. Lathrop (A'35) has been transferred by the New York Power and Light Company from Schenectady to Mahopac, N. Y., where he is operator of the Carmel substation.

Obituary

Albert Gould Davis (A'98, M'00, F'12) patent lawyer and former vice-president in charge of patents of the General Electric Company, died in New York, N. Y., April 25, 1939. Born October 19, 1871, at Brooklyn, N. Y., Mr. Davis was graduated in electrical engineering from Massachusetts Institute of Technology in 1893, and received the degrees of bachelor and master of laws in 1896 and 1897, respectively, from the National University law school, Washington, D. C. In 1893–94 he was in charge of design and construction of furnaces for the Davis-Colby Ore Roaster Company, in Kentucky and Alabama. He became an assistant examiner in the United States Patent Office, Washington, D. C., in 1894, leaving that position in 1896 to engage in private patent-law practice. In 1897 he was made manager of the patent-law department of the General Electric Company, Schenectady, N. Y., and continued in that position until 1919 when he was made vice-president in charge of patents. Shortly after the incorporation of the Radio Corporation of America in 1919, Mr. Davis became a director of that organization, having had an active part in the negotiations by which the Marconi Wireless Telegraph Company of America acquired assets and patents, later purchased by RCA, from its parent company, Marconi's Wireless Telegraph Company, Ltd., London, England. He remained a director until the relationship between General Electric and RCA was dissolved in 1932. The following year he retired from the General Electric Company and became a consulting member of the firm of Pennie, Davis, Marvin, and Edmonds, New York, N. Y. From 1937 until his death he was engaged in independent law practice at 30 Rockefeller Plaza, New York, N. Y. He was president of the New York State Patent Law Association and a member of several other legal organizations.

John Jameson Gibson (A'02, M'12, F'18) retired vice-president, Westinghouse Electric Supply Company, New York, N. Y., died in Philadelphia, Pa., May 6, 1939. Born in York, Pa., November 23, 1872, he graduated from Lehigh University in 1895 with the degree of electrical engineer, and entered the student course at Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. In 1896 he was employed by the American Telephone and Telegraph Company as inspector in the New York district, then as manager of the

seventh district with headquarters at Norfolk, Va., and by the Southern Bell Telephone and Telegraph Company as manager of the Richmond and later the Norfolk district. In 1900 he returned to the Westinghouse company as manager's assistant in the Chicago office, where he later became sales engineer and manager of the industrial division. He was transferred to the Philadelphia office in 1905 as sales engineer, and was district manager 1906–14. In 1915 he was appointed manager of the supply department of the company at East Pittsburgh, and continued in that position until 1922, when he became vice-president and general manager of Westinghouse Commercial Investment Company, New York, N. Y. The latter organization developed into the present Westinghouse Electric Supply Company, with which Mr. Gibson continued in the same capacity until his retirement in 1932. After retirement he was president of the Cresheim Arms Company, managing the hotel of that name in Philadelphia. He was a member of the Franklin Institute, Philadelphia, and had served on its board of managers.

Herbert William Crozier (A'03, M'12) consulting engineer, died at Covina, Calif., April 13, 1939. Born at San Francisco, Calif., June 28, 1875, he graduated from the University of California in 1899 with the degree of bachelor of science. He was employed in engineering capacities by the Harvard Mine, Jamestown, Calif., the Tuolumne County (Calif.) Water Company, and the Cananea Consolidated Copper Company, Cananea, Mex., until 1902, when he became an electrical engineer for the department of electricity of the City of San Francisco. Later he engaged in construction work on the staff of R. S. Masson, electrical engineer, on the Pacific Electric Railway, and other lines, and then became associated with the consulting engineering firm of Sanderson and Porter, San Francisco, Calif., later becoming manager of the San Francisco office of the firm. During the latter years of his life he was an independent consulting engineer, with offices in San Francisco and later in Las Vegas, Nev. He was connected with a number of governmental power projects, being consulting engineer for the state of Nevada, 1923–26, for the Nevada Colorado River Commission, 1927–28, the Central Valley project, 1935, and supervising the design and construction of the power line from Boulder Dam to the Pioche mining region of Nevada, 1936–37. He was a member of the American Society of Mechanical Engineers.

Edouard Roth (A'18) chief engineer of technical services of La Société Générale de Constructions Électriques et Méchaniques, "Alsthom," Paris, France, died April 29, 1939. He was born at Mulhouse, Alsace, January 17, 1878, and graduated from the École Polytéchnique Féderale, Zurich, Switzerland, in 1900. The same year he entered the technical service of the Société Alsacienne de Constructions Méchaniques at Belfort, and later became chief engineer for a-c apparatus. He assumed the position which he held until his death when the Société Alsacienne consolidated with the Compagnie Française–Thomson Houston to form the "Alsthom" organization during the 1920's. Mr. Roth was responsible for many important turbine-generator installations in Paris and other French cities. He was a member of the Société Française des Électriciens, and was active in the International Electrotechnical Commission, serving on various committees, and in other ways participating in international standardization activities. He was the author of many technical papers and articles, and made important contributions to the design and construction of electrical machinery. He was a Chevalier of the Legion of Honor, and had received the silver medal of the Industrial Society of Mulhouse, the Hebert prize of the French Academy of Science (1925), and other honors and awards for his work.

Emmet Grattan Ralston (A'21, M'34) vice-president and general manager of the Indianapolis Power and Light Company, Indianapolis, Ind., died April 17, 1939. He was born in Lebanon, Ind., October 28, 1890, and graduated from Purdue University with the degree of bachelor of science in electrical engineering, in 1913. The same year he was employed by the Indianapolis Light and Heat Company, first as a meter tester, then in charge of demand testing. He continued with that company as underground superintendent, design engineer, chief engineer of Mill Street station, electrical superintendent, chief engineer, and operating vice-president. He remained in the last position when the company, as the result of a merger, became the Indianapolis Power and Light Company, and in 1930 became a member of the board. He had held the position of vice-president and general manager for about three years. He was a member and former president of the National Association of Power Engineers and also of the Indiana Electric Association, and at the time of his death was president of the Indianapolis Electric League.

William Cramp (M'26) professor of electrical engineering at the University of Birmingham, England, died April 20, 1939, at Llandudno, Wales. Born January 8, 1876, at Coventry, England, he received the degrees of master of science at the College of Technology, Manchester, and doctor of science at the University of Manchester. He was an engineer apprentice from 1892 to 1897, when he became assistant to the works manager of Ferranti, Ltd., Hollinwood. In 1900 he was appointed lecturer in electrical design at the Imperial College of Science and Technology, London. From 1905 to 1920 he was a member of the firm of Cramp and Frith, consulting engineers, Manchester, and also acted as a lecturer in electrical design and technology at the University of Manchester. He was appointed professor of electrical engineering at the University of Birmingham in 1920. Professor Cramp was the author of books and articles on technical subjects, and a member of the Institution of Electrical Engineers, having served on the council of that society.

Emerson Pierce Peck (A'08, M'20, F'23) consulting engineer, Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., died November 14, 1938, according to information recently received. Mr. Peck was born at Atlanta, Ga., August 13, 1882, and studied at the Georgia School of Technology. In 1905 he was employed by the Georgia Railway and Electric Company, Atlanta, and in 1906 became foreman of the testing department, in 1914 superintendent of tests and repairs department, and in 1916 superintendent of operation. In 1918–19 he served as a technical expert for the United States Bureau of Standards and the War Department. He became general superintendent of the electrical department, Utica (N. Y.) Gas and Electric Company in 1919, later becoming a vice-president of the company. Subsequently he became associated with the New York Power and Light Company, Albany, N. Y., as an engineer on special studies, and was later employed in the same capacity by the Buffalo, Niagara, and Eastern Power Corporation.

Loren H. Shute (A' 15) superintendent, electrical division, Light and Power Department of the City of Colorado Springs Colo., died in Agua Caliente, Ariz., February 10, 1939. He was born in Denver, Colo., October 1, 1883, and attended high school there, afterward being employed in the shops of the Denver Gas and Electric Company 1902–05. For the next four years he was engaged in installing electrical and mining machinery for the Yak Mining, Mill and Tunnel Company, Leadville, Colo. In 1908 he was employed by the Central Colorado Power Company, Denver, on construction and transmission work, becoming superintendent of operations in 1912 and general superintendent of all properties in 1914. He continued in the last-named position until 1922, when he moved to California on account of health. In 1924–25 he was a line specialist for Western Electric Company, Denver, Colo., and in 1925 he assumed the position at Colorado Springs which he held until his death.

Thomas Hesketh (A'04, M'06) director, Folkestone Electricity Supply Company, Ltd., Folkestone, England, died in March 1939. He was born at Lytham Lanes, England, April 19, 1873, and educated at the Durham College of Science, Newcastle-on-Tyne. He later served an apprenticeship of three years with J. H. Holmes and Company of the same city. In 1892 he was appointed chief engineering assistant at the Blackpool (Eng.) Electricity Works, and in 1895 took the position of electrical engineer at the electric light plant of Madrid, Spain. He was appointed engineer and manager of the Folkestone Electricity Supply Company in 1898, having charge of the design and construction of the station and later managing it. In 1923 he became managing director of the company, and later director. He was a member of the Institution of Electrical Engineers and the Institution of Mechanical Engineers, both of Great Britain.

Ernest Joseph Sterba (A'21, M'35) member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., died

April 24, 1939, at Asbury Park, N. J. He was born in Iowa City, Iowa, June 29, 1896, and received the degree of bachelor of engineering in electrical engineering from the University of Iowa, where he was an assistant instructor of physics in 1919–20. During 1920 he was a research engineer for Western Electric Company, New York, N. Y., and from that time until his death was engaged in research and development of radio transmission equipment for the Bell Laboratories. He was a member of the Institute of Radio Engineers and author of many technical articles.

William Sterling Fields (A'25) senior power engineer, American Rolling Mill Company, Ashland, Ky., died March 9, 1939. He was born March 9, 1901, at Sadieville, Ky., and received the degree of electrical engineer from the University of Cincinnati in 1924. From 1918 to 1924 he was employed in various capacities by the Union Gas and Electric Company, Cincinnati, Ohio. In 1924 he became supervisor of tests and power distribution for the American Rolling Mill Company, later becoming technician in the electrical power department, and senior power engineer, the position which he held at the time of his death.

Albert Rolaz Gallatin (A'98) member of the brokerage firm of Smith and Gallatin, New York, N. Y., died in March 1939. Born in New York October 4, 1869, he received the degree of bachelor of arts in 1891 from Columbia University, where he later studied electrical engineering. He was associated with Smith and Gallatin for more than 30 years.

Membership

Recommended for Transfer

The board of examiners, at its meeting on May 18, 1939, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Keath, H. B., engineer, in charge of transformer div. Wagner Electric Corporation, St. Louis, Mo.
Lisberger, S. J., chief, division of electric distribution, Pacific Gas and Electric Company, San Francisco, Calif.
Milburn, L. R., electrical engineer, Great Lakes Steel Corporation, Detroit, Mich.
Stein, I. Melville, director of research, Leeds and Northrup Company, Philadelphia, Pa.

4 to Grade of Fellow

To Grade of Member

Bass, J. H., equipment engineer, Southwestern Bell Telephone Company, Oklahoma City, Okla.
Black, R. A., foreign trade manager, Ohio Brass Company, Mansfield.
Briggs, A. F., assistant electrical superintendent, Sun Oil Company, Beaumont, Tex.
Chase, D. D., central station department, General Electric Company, Schenectady, N. Y.
Christenbury, F. L., superintendent of meter and relay division, Memphis Power and Light Company, Memphis, Tenn.
Embree, J. N., assistant distribution engineer, Union Electric Company of Missouri, St. Louis.
Harkins, J. M., electrical engineer, Hydroelectric Power Commission of Ontario, Toronto, Ont., Can.
Henderson, M. L., electrical engineer, General Electric Company, Pittsfield, Mass.
Ibach, W. R., assistant customer's substation engineer, Wisconsin Electric Power Company, Milwaukee.
Jones, J. L., plant supervisor, Southwestern Bell Telephone Company, Oklahoma City, Okla.
Kerrigan, A. L., electrical engineer, Fitchburg Gas and Electric Light Company, Fitchburg, Mass.
Laffoon, C. M., engineering manager, a-c generator engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Lyons, S. H., building and equipment engineer, Southwestern Bell Telephone Company, Oklahoma City, Okla.
Malsbary, J. S., electrical engineer, Wagner Electric Corporation, St. Louis, Mo.
McCluskey, F. J., assistant chief engineer, James R. Kearney Corporation, St. Louis, Mo.
Michael, J. H., assistant engineer, Allis-Chalmers Company, Milwaukee, Wis.
Mollman, L. A., electrical engineer, Union Electric Company of Missouri, St. Louis.
Muir, A. C., electrical engineer, The Berwind-White Coal Mining Company, Philadelphia, Pa.
Poole, F. L., assistant professor of electrical engineering, University of Utah, Salt Lake City.
Prosser, R. A., electrical shop department head, Seneca Vocation High School, Buffalo, N. Y.
Robinson, C. P., synchronous division engineer, The Ideal Electric and Manufacturing Company, Mansfield, Ohio.
Sampson, C. L., engineer of transmission, protection and plant extension, Northwestern Bell Telephone Company, Des Moines, Iowa.
Summers, C. M., electrical engineer, General Electric Company, Fort Wayne, Ind.
Teague, W. L., engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Timoshenko, Gregory S., instructor in electrical engineering, Massachusetts Institute of Technology, Cambridge.
Wells, F. J., junior engineer, New York and Queens Electric Light and Power Company, Flushing.
Whitlow, C. S., application engineer, General Electric Company, St. Louis, Mo.
Wyatt, K. S., technical director, Enfield Cable Works, Ltd., Middlesex, England.

28 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before June 30, 1939, or August 31, 1939, if the applicant resides outside of the United States or Canada.

United States and Canada

1. North Eastern

Camerlengo, J. M., General Electric Company, Pittsfield, Mass.
Dickman, K. W., Harvard Business School, Boston, Mass.
Engel, O. W. (Member), International General Electric Company, Schenectady, N. Y.
Krishnan, L. M., Massachusetts Institute of Technology, Cambridge, Mass.
Ritter, J., Stromberg Carlson Telephone Manufacturing Company, Rochester, N. Y.
Rumsey, A. L. (Member), New York Telephone Company, Albany, N. Y.
Sutton, C. E., Jr., General Electric Company, Pittsfield, Mass.
Thompson, L. W., General Electric Company, Schenectady, N. Y.

2. Middle Eastern

Askey, J. S., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Blair, C. J., Ideal Electric and Manufacturing Company, Mansfield, Ohio.
Blatt, R. C. (Member), care of Municipal Architect of the District of Columbia, Washington, D. C.
Brown, H. M., United States Patent Office, Washington, D. C.
Giles, M. A., Ohio Public Service Company, Mansfield, Ohio.
Langevin, L. J., Westinghouse Electric and Manufacturing Company, Cincinnati, Ohio.
McCabe, D. (Member), Davison Chemical Company, Baltimore, Md.
McLaughlin, J. W. M., National Defense Power Committee, Washington, D. C.

3. New York City (Territory of the New York Section)

Alford, A., Mackay Radio and Telegraph Company, New York, N. Y.
Campbell, J. W. (Member), American Telephone and Telegraph Company, New York, N. Y.
Dunn, J. W. (Member), Public Service Electric and Gas Company, Newark, N. J.
Felch, E. P., Jr. (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Pease, R. M., Philco Radio and Television Corporation, New York, N. Y.
Plank, C. S. (Member), American Telephone and Telegraph Company, New York, N. Y.
Ruze, J., Signal Corps Laboratories, Fort Monmouth, N. J.
Swart, L. K., Bell Telephone Laboratories, New York, N. Y.
Whitmore, P. G. (Member), Ebasco Services Inc., New York, N. Y.

4. Southern

Blackburn, L. A. (Member), Slaughter Saville and Blackburn, Inc., Richmond, Va.
Mathews, W. E., Carolina Aluminum Company, Badin, N. C.

5. Great Lakes

Bartholomew, D., University of Minnesota, Minneapolis.
Blanchett, L. E., Bucyrus Erie Company, South Milwaukee, Wis.
Bullen, C. V., Barber-Colman Company, Rockford, Ill.
Hanna, R. C., General Electric Company, Fort Wayne, Ind.
Johnson, R. H., General Electric Company, Fort Wayne, Ind.
Kahler, W. V. (Member), Illinois Bell Telephone Company, Chicago, Ill.
Kilgour, A. B., Commonwealth and Southern Corporation, Jackson, Mich.
Poole, W. C. (Member), Sinclair Refining Company, East Chicago, Ind.
Schwandt, G. O., General Electric Company, Fort Wayne, Ind.
Stites, H. E., Commonwealth and Southern Corporation, Jackson, Mich.

6. North Central

McCormick, H. T., 43 Blair Avenue, Rock Springs, Wyo.

7. South West

Bromagem, J., Southwestern Bell Telephone Company, Fort Worth, Tex.
Coryell, W. R., Jr. (Member), S. C. Sachs Company, St. Louis, Mo.
December, F. O., Houston Lighting and Power Company, Houston, Texas.
Farmer, L. L., Nevada Consolidated Copper Corporation, Hurley, N. Mex.
Gehm, E. S., Union Electric Company of Missouri, Webster Groves.
Glenn, V. T., Mid-west Electric Cooperative Association, Rotan, Texas.
Phinney, J. M., Black and Veatch, Kansas City, Mo.
Stonecipher, G. A., Mountain States Telephone and Telegraph Company, El Paso, Texas.

8. Pacific

Bertram, E. C., North American Aviation, Inc., Ingelwood, Calif.
Collins, I. W., Pacific Gas and Electric Company, Oakland, Calif.
Dutter, D. D., Southern California Edison Company, Ltd., Los Angeles, Calif.
Looper, F. B., Los Angeles Bureau Power and Light, Boulder City, Nev.
Lough, H. N., Southern California Edison Company, Ltd., Colton, Calif.
Muller, C. R., United States Navy Yard, Pearl Harbor, T. H.
Porter, J. C., General Electric Company, Los Angeles, Calif.
Shideler, J. H., Route 2, Box 330, Hemet, Calif.
Strong, R. T., Westinghouse Electric and Manufacturing Company, San Diego, Calif.
Thomas, W. C. (Member), Southern California Telephone Company, Los Angeles, Calif.

9. North West

Arnett, H. E., Portland General Electric Company, Portland, Ore.
Canada, C. B. (Member), General Electric Company, Portland, Ore.
Wing, W. C., Pacific Telephone and Telegraph Company, Spokane, Wash.

10. Canada

Lillie, H., Bruce Peebles and Company, Ltd., Montreal, Que.
Peebles, R. M., Canadian Westinghouse Company, Hamilton, Ont.
Smeaton, J. M., Dominion Cutout Company Toronto, Ontario, Canada.

Total, United States and Canada—62

Elsewhere

Veglery, A., Socony Vacuum Oil Company, Inc., Istanbul, Turkey.
Sarma, T. N. R., Poona Electric Supply Company Ltd., Poona, India.
Piazza, T. L., Compania Italo Argentina de Electricidad, Buenos Aires, South America.

Total, elsewhere—3

Engineering Literature

New Books in the Societies Library

Electrical engineers may be interested in the following new books, which are among those recently received at the Engineering Societies Library, New York, N. Y. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the preface of the book in question.

THEORY OF LUBRICATION. By M. D. Hersey. New York, John Wiley and Sons, 1938. 175 pages, diagrams, etc., 9 by 6 inches, cloth, $2.50. Aims to give a balanced picture of the scientific background of modern lubrication. The topics considered are viscosity, the hydrodynamical and dimensional theories, temperature rise in bearings, and the problem of oiliness. A section on recent developments has been added to this edition. Bibliographies accompany each section.

WATER SUPPLY ENGINEERING. By H. E. Babbitt and J. J. Doland. Third edition. New York and London, McGraw-Hill Book Company, 1939. 690 pages, illustrated, 9 by 6 inches, cloth, $6.00. A comprehensive introductory textbook presenting material on finances, hydraulics, ground water and wells, dams and mechanical equipment, electrical equipment, distribution systems, filtration, and the analysis, softening, and purification of water.

THE THEORY of MACHINES. By T. Bevan. London and New York, Longmans, Green and Company, 1939. 549 pages, diagrams, etc., 9 by 6 inches, cloth, $5.40. Following a brief résumé of the principles of elementary mechanics, the succeeding chapters deal with the various fundamental types of mechanisms, such as gears, cams, belt drives, etc., and discuss the subjects of vibration and balancing. To facilitate the graphical solution of problems, diagrams have been carefully drawn to scale. The answers to the problems given with the text are collected in the back of the book.

HYDRAULICS FOR ENGINEERS AND ENGINEERING STUDENTS. By F. C. Lea. Sixth edition. New York, Longmans, Green and Company, 1938. 787 pages, illustrated, 9 by 6 inches, cloth, $6.75. The opening chapters deal with the basic characteristics of fluids at rest and in motion. The several chapters following contain a detailed analysis of the flow of water over weirs, through orifices and pipes, and in open channels, as well as of gauging practice. A chapter on the impact of water on vanes is introductory to the description and analysis of water wheels, turbines, centrifugal and reciprocating pumps, and other hydraulic machines. Streamline motion and dynamical similarity are briefly discussed.

SPECIFICATION DOCUMENTS FOR BUILDING MATERIALS and CONSTRUCTION. Los Angeles, Calif., Pacific Coast Building Officials Conference, 1938. 386 pages, diagrams, etc., 8 by 5 inches, cloth, $4.00. The specifications in this volume form part of the Uniform Building Code of the Pacific Coast Building Officials Conference. They include those on building materials, standards of fire resistance, and building appurtenances and equipment published by various national engineering organizations and adopted by the Conference.

INCHLEY'S THEORY OF HEAT ENGINES. Edited and revised by H. W. Baker. New York and London, Longmans, Green and Company, 1938. 345 pages, diagrams, etc., 9 by 6 inches, cloth, $3.60. Considerably changed from the original book, this new edition retains the author's idea "to give in a complete and concise form the thermodynamical principles of the subject." Fundamental general principles and then the more specific applications are considered respectively before the discussion of devices: air compressors and motors, reciprocating engines, steam turbines, internal combustion engines, and mechanical refrigerators. Heat transfer, combustion, and test methods are also included.

INDEX TO ASTM STANDARDS AND TENTATIVE STANDARDS, January 1939. Philadelphia, Pa. American Society for Testing Materials, 1939. 128 pages, 9 by 6 inches, paper, free upon application. A convenient guide to the current state of standardization by the society, indexing all the specifications, test methods, and definitions now in force, regardless of the volumes in which they appear. Over 800 specifications are indexed under appropriate headings.

SECOND REPORT ON VISCOSITY AND PLASTICITY. Prepared by the Committee for the Study of Viscosity of the Academy of Sciences at Amsterdam. N. V. Noord-Hollandsche Uitgeversmaatschappij, Amsterdam; New York, Nordemann Publishing Company, 1938. 282 pages, illustrated, 11 by 7 inches, cloth, $7.50. The first report of this Committee appeared in 1935. The second report includes surveys of further developments treated in the first, and also a discussion of problems concerning the internal structure of liquids. Among the topics considered are the relation of the viscosity of liquids to their chemical and physical constitution, the motion of small elongated particles in a viscous liquid, the yield value, recent plastometers, and technical capillary viscosimeters.

TENSOR ANALYSIS OF NETWORKS. By G. Kron. New York, John Wiley and Sons, 1939. 635 pages, diagrams, etc., 9 by 6 inches, cloth, $7.50. Presents a new method of approach to the analysis and synthesis of networks through the use of tensors and spinors. Although the book deals specifically with the organization of those sets of linear, algebraic equations occurring in the study of asymmetrical active networks having lumped constants, it also constitutes an introduction to similar applications of tensor analysis in other engineering fields.

DIESEL ENGINES, THEORY AND DESIGN. By B. E. Degler. Chicago, American Technical Society, 1939. 270 pages, illustrated, 9 by 6 inches, cloth, $2.50. A practical elementary text which uses only elementary mathematics, intended for evening school classes and home study. Thermodynamics, fuels and combustion, and testing are considered, together with the principles of design and the design of engine parts.

HIGHER MATHEMATICS. By R. S. Burington and C. C. Torrance. New York and London, McGraw-Hill Book Company, 1939. 844 pages, diagrams, etc., 9 by 6 inches, cloth, $5.00. Designed primarily for students interested in the applications of mathematics to physics and engineering, the concepts presented have been developed with sufficient rigor to be suitable as well for students of pure mathematics. Of the following topics the physical meanings of the various notations and relationships have been emphasized, with the help of numerous examples and exercises: advanced differential and integral calculus; differential equations; infinite series; functions of a complex variable; vector analysis; and the calculus of variations.

LIGHT. By F. Bray. Second edition. London, Edward Arnold and Company; New York, Longmans, Green and Company, 1938. 369 pages, illustrated, diagrams, etc., 8 by 5 inches, cloth, $2.50. The field of optics is covered quite fully in this elementary textbook, the subject matter including the fundamental phenomena of propagation, reflection, and refraction, description of the eye and various optical instruments, and discussions of diffraction, polarization, and spectra. Questions with answers are included.

NUMBER, THE LANGUAGE OF SCIENCE. By T. Dantzig. Third edition. New York, The Macmillan Company, 1939. 320 pages, illustrated, 9 by 6 inches, cloth, $3.00. An account of the manner in which our concept of number has developed from finger counting into the modern science, written with a minimum of technicalities for the non-mathematically educated reader. A group of twenty-six short articles on technical, historical, and philosophical matters has been added in this edition.

THE FUNDAMENTALS OF ELECTRO-MAGNETISM. By E. G. Cullwick. Cambridge, England, University Press; New York, The Macmillan Company, 1939. 352 pages, illustrated, 9 by 6 inches, cloth, $4.50. Starting with electrostatics and continuing through permanent magnets to electro-magnetic waves, the theory of electromagnetism is here developed on the basis of demonstrable physical concepts, discarding, along with the unit magnetic pole, the attempt to establish and utilize an actual electro-magnetic field. Either the orthodox units or the new meter-kilogram-second practical system may be applied. Many examples and problems are included.

PRACTICAL ELECTRIC ILLUMINATION AND SIGNAL-WIRING METHODS. By T. Croft. Revised by G. H. Hall. Third edition. New York and London, McGraw-Hill Book Company, 1939. 351 pages, illustrated, 8 by 6 inches, cloth, $3.00. Gives rules, methods, diagrams, and other data useful for many electrical jobs. In the illumination field will be found analyses of lighting requirements, design of circuits, and selection and installation of fixtures, including mercury and sodium vapor lamps. Methods for signal wiring work are given in line with Code requirements. Many signal circuit diagrams.

PHYSICAL SCIENCE IN MODERN LIFE, By B. G. Richardson. New York, D. Van Nostrand Company, 1939. 256 pages, illustrated, 8 by 5 inches, cloth, $3.00. An account intended for the general reader, of some recent developments in physics. The subjects chosen touch everyday existence. Streams and eddies, vibrations and waves, colloids, heat, light, electricity, sensation and reaction are among the matters considered.

NEON TUBE PRACTICE. By W. L. Schallreuter. Second edition, revised. New York, Chemical Publishing Company, 1939. 255 pages, illustrated, 9 by 6 inches, cloth, $4.25. The opening section covers in a simplified manner the theory involved; gaseous conduction of electricity, electrodes, vacuum technique, etc. The next section explains tube manufacture, practical uses, and methods of installation. Various causes of failures are subsequently treated, and the final section is devoted to special tubes and discharge lamps, including mercury and sodium vapor lamps.

MODERN MAGNETISM. By L. F. Bates. Cambridge, England, University Press; New York, The Macmillan Company, 1939. 340 pages, diagrams, etc., 9 by 6 inches, cloth, $4.50. Attempts to treat the subject from the experimental rather than the theoretical point of view. Prominence is given to a description of fundamental experiments, and accounts are given of much experimental work, particularly foreign work, of importance to those interested in industrial applications of magnetic materials.

THE MANAGEMENT OF MUNICIPAL PUBLIC WORKS. By D. C. Stone. Chicago, Public Administration Service, 1939. 344 pages, diagrams, etc., 10 by 7 inches, cloth, $3.75. The science of management as developed in industrial plants is here applied to municipal public works administration. Based on actual practice, the material covers all phases of accounting, purchasing, administration, etc., including many illustrations of sample forms. May serve as a reference manual as well as a textbook.

THE JOURNAL OF THE ROYAL TECHNICAL COLLEGE. Volume IV, Part 3, January 1939, pages 421–605. Glasgow, Scotland, Royal Technical College. Illustrated, 9 by 7 inches, paper, 10s. 6d. This publication constitutes a record of some of the research work carried out in the college by the staff and senior students. The topics include investigations in physical chemistry, metallurgy, mechanics, electrical measurements, photo-elasticity, etc.

HOCHFREQUENZTECHNIK. Two volumes. (Lehrbücher der Feinwerktechnik, edited by K. Gehlhoff.) By J. Kammerloher. Leipsig, C. F. Winter'sche Verlagshandlung, 1938–39. Diagrams, etc., 8 by 6 inches. Volume I, 199 pages, paper 6.90 rm., bound, 7.60 rm.; Volume II, 326 pages, paper, 11.50 rm., bound, 12.80 rm. In the first volume the theory and characteristics of electromagnetic oscillatory circuits are developed, covering capacitors and inductances in general, various closed and open circuits, losses, and calculation fundamentals. The second volume considers the fundamentals and characteristics of diodes, triodes, and multi-grid electron tubes, diagrammatic of varying a-c voltages, and sound-frequency amplifiers, including comparisons of theoretical with experimental values.

ALTERNATING-CURRENT BRIDGE METHODS. By B. Hague. Fourth edition. New York and Chicago, Pitman Publishing Corporation, 1938. 387 pages, diagrams, etc., 9 by 6 inches, cloth, $8.50. This new edition contains theoretical and practical information dealing with a-c bridges for the measurement of inductance, capacitance, and effective resistance at low and telephonic frequencies. The separate chapters cover fundamentals, symbolic theory, apparatus, the classification of bridge networks, and the various available methods, including necessary precautions.

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Transactions

Papers and Discussions Comprising Pages 243–306 of the 1939 Volume

Considerations in Applying Ratio Differential Relays for Bus Protection

By R. M. SMITH ASSOCIATE AIEE W. K. SONNEMANN ASSOCIATE AIEE G. B. DODDS ASSOCIATE AIEE

THE PROBLEM of bus differential protection is receiving increased attention by relay engineers because of the serious consequences of a bus fault. Several cases of bus faults have recently occurred indicating that regardless of care used in the design of structures, some unexpected failure or accident may cause a disastrous outage. In spite of the many improvements that have been made in the protection of transmission lines in recent years, little attention has been given to the protection of station busses. This has been due partly to the impression that they were not particularly subject to faults and partly to the feeling that the protective relays would do more harm than good through incorrect tripping. Recent experiences, however, indicate that a bus fault, though of infrequent occurrence, can cause much greater damage and a longer outage period than many transmission line faults. Also, high-grade performance has been obtained when a bus protective scheme is properly installed with due consideration given to the many factors which might lead to faulty operation. The purpose of this paper is to discuss some of the important factors to be considered in bus differential protection and the operating characteristics and results of a field test on a new bus differential relay.

The differential relaying scheme for protecting a station bus does not differ in principle from that which has long been used for the protection of a generator or transformer bank. That is, current transformers are located in all connections to the bus and a summation of all the secondary currents is made (figure 1). Under load conditions or for an external fault the summation of all the currents should equal zero, and, therefore, no current should appear in the operating winding of any relay connected across that circuit. For an internal fault, assuming faithful current-transformer response, the total amount of the short-circuit current should appear in the operating winding of the protective relay.

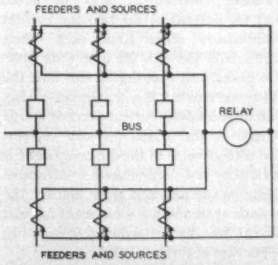

Figure 1. Differential protection for a six-circuit bus using an overcurrent differential relay

Current-Transformer Performance

A-C Saturation

In the case of a fault occurring external to the differential zone, the operating coil of the relay would receive no current whatsoever, if the performance of the current transformers was perfect. Actually, current often does appear in the operating coil of the relay upon the occurrence of external faults because of unfaithful transformer performance. Any one or more of the current transformers involved may be affected by a-c saturation because of insufficient iron in the current transformer core, an insufficient number of secondary turns, or excess burden in the secondary circuit for the magnitude of current involved. In general, the effect of a-c saturation has not been found to be particularly bad for differential relay protection.

D-C Saturation

A second and more important factor affecting current-transformer performance, which has not been fully appreciated, is that arising from the effect of the d-c component of asymmetrical faults. The introduction of faster operating differential relays has brought this problem to the front, since with the slower operating relays formerly used, the effects of the d-c transient were over before tripping could occur. The effect of the d-c component of an asymmetrical current wave is such as to aggravate the saturation of current transformers to a far greater degree than the corresponding a-c component. The effect of this d-c component on the current transformer is to magnetize the current transformer core with a unidirectional flux which thus gives rise to the term d-c saturation of current transformers. The degree of this effect depends upon the d-c time constant of the primary circuit, the resistance and inductance of the secondary circuit of the current transformer affected, the amount and magnetic characteristics of the core, the ratio of the current transformer, and the magnitude of the primary current. The degree of d-c saturation is greater for the longer d-c time constants. This makes the problem more difficult, particularly for the protection of generator busses, since the time constant for a large generator may be as great as 0.3 seconds. High-voltage busses will, in general, have a time constant less than 0.3, ranging in value from approximately 0.13 down to 0.05, or even less if the bus is located a considerable distance from the generating station.

Matched Current Transformers

On first thought it would seem practical to insure adequate performance of current transformers for differential protection by making all of the current transformers alike. However, it is found that even with standard current transformers built to the same specifications, there still remains some difference in their perform-

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1. For all numbered references, see list at end of paper.

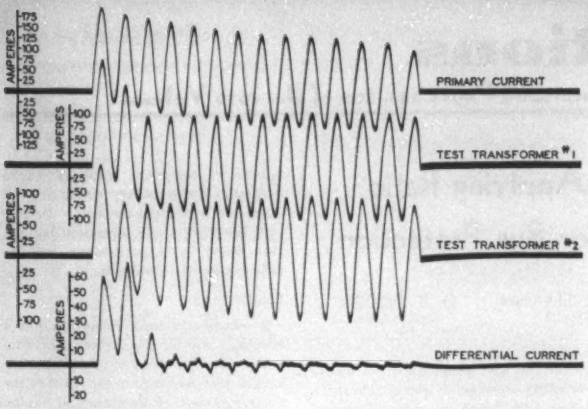

Figure 2. Oscillogram showing effect of d-c saturation

ance when subjected to asymmetrical short circuits. This is because their saturation curves will not match exactly at the high values of d-c excitation involved. Another reason why duplicate standard current transformers used throughout will not always give satisfactory performance is because the total short-circuit current may flow out to an external fault through one current transformer, but may be divided up among several current transformers in the leads to the bus from the various sources. For example, with a generator bus having two generators and two bus-tie breakers, an external fault of 60,000 amperes on a feeder may be divided up into 20,000 amperes feed-in through each bus-tie breaker and 10,000 amperes from each generator on the bus section. Obviously the current transformer in the outgoing feeder which must carry 60,000 amperes will be operating on a different portion of the saturation curve than the current transformers on the incoming leads. Therefore, unless the current transformer in the feeder circuit has been designed so that it will not saturate with an asymmetrical short circuit of 60,000 amperes, a difference or operating current is bound to occur for this type of fault in spite of any effort made to match the current transformer characteristics for symmetrical currents.

A more complete discussion of the effect of d-c transients on current transformer performance is available elsewhere.[1] However, no simple method has yet been made available which can be used to determine accurately the magnitude and duration of the difference in current transformer output for these conditions.

Figure 2 shows an actual test film in which two differentially-connected transformers were caused to saturate by d-c transient current. It may be noted that the outputs of the two test current transformers differ from each other, particularly through the first three positive peaks, and that during this time the difference current is a maximum. Also, neither secondary current records a true picture of the actual primary current. The correct value of the d-c component is obviously not reproduced. Measurements on the film also show that for the seventh cycle the a-c component for test current transformer number 2 was only 83 per cent of the true value.

Blocking Resistors

One means of controlling the amount of difference current which may flow is by inserting a definite amount of fixed resistance in the difference or operating coil circuit. A well-accepted practice for improving the performance of differential protection has been the reduction and balancing of lead impedance in the secondary circuit and the increase of impedance in series with the differential relay. For example, many operating companies make a practice of running all current-transformer secondary leads in the differential circuit to a bus out in the switch yard, when only a single-element overcurrent relay is used, and then bringing to the relay only the necessary leads. This results in a minimum of secondary lead resistance to each current transformer secondary and does increase the burden in the differential circuit by the extent of the lead resistance to the relay. Several recent installations have extended this principle by the addition of a resistance in series with the operating winding of the differential relay in order to decrease the current through this path in case of an external short circuit. Recent tests have indicated that with ratio differential relays some discretion must be observed in the magnitude of resistance to be introduced in the differential circuit or failure to trip for an internal fault might result. This comes about from the fact that the secondary voltage of the current transformers required to force the differential current through the excess burden may reach a high value. As a result, the poorer current transformer may not be able to develop this voltage and is subjected to a reversal of current through its secondary. In other words, one current transformer may actually have its secondary current reversed so that a differential relay having restraint windings wound on the same magnetic circuit would not have the restraint torque canceled out, as should occur on an internal fault with this type of relay. Therefore, a failure to trip might easily occur, if the impedance in series with the operating winding is too high.

Figure 3 illustrates a test condition wherein too much impedance was used in the differential circuit for an internal fault condition. The polarity of connections was such that had both current transformers performed correctly, the loops of the current wave of current transformer number 1 would have dove-tailed with the primary current wave, while the wave for current transformer number 2 would have been exactly opposite in phase. For the first two cycles, current transformer number 1 reversed the current through current transformer number 2 without excessive wave-form distortion. At the end of two cycles, it will be noted that current transformer number 2 takes control of the circuit, reversing the current through current transformer number 1, accompanied by a severe distortion of wave form.

Without saturation, the output of the two test current transformers should have been 126 amperes each, as determined from their ratio and the magnitude of the primary current. The differential or operating coil current, then, should have been 252 amperes. An approximation of the actual currents flowing at the fifth cycle gives values of 61 amperes for current transformer number 1, 75 amperes for current transformer number 2, and 17 amperes for the difference current. This means that a 50 per cent ratio differential

relay would not have operated for this test, since the ratio of the operating coil current to the smaller restraining coil current is only 28 per cent [(17/61) (100) = 28 per cent].

Differential Relay Schemes

The fact that there are many successful bus differential relays in service at the present time, which are giving a relatively high degree of protection, does not indicate necessarily that difficulties will not be encountered on other systems or on these systems when future changes are made. It is also possible that on some of these installations an improper operation may yet occur because of the proper combination of circumstances. Otherwise, the satisfactory performance of existing installations has resulted from either a sufficiently high current setting or a long enough time to allow the transient to subside. Either of these factors tends to make a simple overcurrent relay satisfactory. There have been cases of false operation on a through fault involving d-c transient in which it is recognized that one or the other of these factors was not sufficiently high.

The magnitude of a phase-to-ground fault where a limited current exists often determines the setting of a differential relay. In such an application the use of a restrained or ratio differential relay would lessen the tendency for incorrect relay operation for heavy through faults. Of course, as pointed out elsewhere,[2] sufficient restraining windings must be provided so that on an external fault, short-circuit current must pass through at least one restraining winding. That is, current transformers must not be paralleled in such a manner that on a through fault on one of these circuits current would circulate between the secondaries of the two paralleled current tranformers. Under this condition only the difference in the outputs of the two current transformers would flow through a restraining winding and the operating winding in series, and the relay would operate as a sensitive overcurrent relay.

Multiple Restraint Relays

Schemes have been proposed for obtaining a restraining winding for each circuit connected to a bus. One of these is to build a relay with numerous restraining elements operating on a common shaft. This method is undesirable from the standpoint of added complexity and practical considerations. For example, if six or more restraining elements are made to operate on one shaft, the length of the shaft becomes unwieldy and serious mechanical problems are introduced. The same results may be achieved by applying two or more ratio differential relays having three restraining windings and so connected that one restraining coil is available for each circuit and both relays must close their contacts to complete the tripping function. For many applications the standard three-element ratio differential relay, such as the type *CA*-4, is satisfactory. An illustration of this scheme is shown in figure 4 for a bus having six lines connected to it. Each circuit has a separate restraining winding and the operating coils of the two relays are connected in series so that on an internal fault both relays will close their contacts.

For more complex bus connections the same scheme can be amplified using three or more relays per phase, but usually a maximum of three relays is all that is required, since careful consideration of the minimum number of sources that

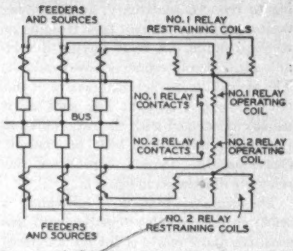

Figure 4. Differential protection using two CA-4 relays per phase

can be connected to the bus at any one time will allow the paralleling of certain current transformers. This means that for all possible bus setups at least two restraining windings will be energized on through faults. For example, operating conditions may be such that for a time no sources of current are connected to the restraining windings of one of the two relays. Upon the occurrence of an external fault this relay would then probably close its contacts. The other relay, however, would have its restraining windings energized in accordance with the current flowing from the active sources to the fault so that its correct performance in failing to close its contacts during an external fault would prevent a false tripping operation.

Variable Ratio Characteristics

The problem becomes more involved if the ratio of maximum through fault current to minimum internal fault current is large. For example, if the system is grounded through an impedance, the operating coil current may be quite limited for a phase-to-ground fault on the bus. If the magnitude of this current in per cent of normal load current is small, a high-sensitivity relay will be required (high sensitivity being synonymous with low percentage ratio). Upon the occurrence of an external interphase fault, however, the current will not be limited by the grounding impedance. If unfaithful current-transformer performance results from these higher currents, it is quite likely that the difference current in per cent of the through or restraining coil current may be high enough to cause the relay to trip. It is obvious from these considerations that the ideal relay for this application should have a variable ratio characteristic. Its percentage ratio should be low at normal currents to furnish sensitive operation for minimum internal faults. Its percentage ratio should be high, correspond-

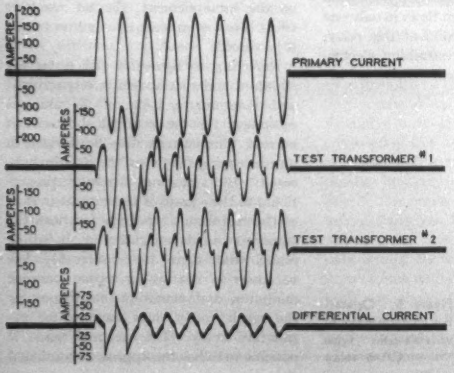

Figure 3. Oscillogram showing effect of a-c saturation and reversal of one current transformer

ing to reduced sensitivity, at the higher fault currents to prevent false tripping on through faults. A relay having a variable ratio characteristic is now available. The operating characteristic curve of this relay is not a straight line such as is usually connected with the ratio differential relay, but has a bent or "flared" characteristic. Typical curves for this relay are illustrated in figure 5.

The ordinary remedy of providing a sensitive ground relay together with less sensitive phase relays is not the universal answer to the above problem, particularly where d-c transients are involved. In such an application, the occurrence of an external three-phase fault will result in maximum, or very nearly maximum, d-c component in at least one of the three phases. The current transformers in this phase will saturate more severely than those in the other two phases receiving less d-c component. The resulting unbalance in the secondary currents will flow through the ground relay circuit, and thus tend to cause false operation of a sensitive relay.

The problem of securing the flared characteristics, as illustrated, is quite involved in a multirestraint relay where the torques vary approximately as the square of the current. In the standard type *CA*-4 relay there are three restraining windings and one operating coil winding which have been so proportioned on their respective electromagnets to give approximately straight-line characteristics. It would appear, on first sight, that in order to bend the straight-line characteristic it would only be necessary to increase the turns on the operating coil to increase the sensitivity of the relay at low restraint currents, and then allow the operating element to saturate in order to obtain lower sensitivity at higher fault currents. Such would be the case provided that the particular restraint conditions could be chosen and held constant, which they obviously cannot be. For example, if 60 amperes secondary were involved in a through fault and this current was equally divided between the three restraining windings, the torque per restraining element would be proportional to $3(20)^2 = 1{,}200$. On the other hand, if the current were divided between two restraining windings, 30 amperes in each, the restraining force would be proportional to $2(30)^2 = 1{,}800$. If the total secondary current flows in only one restraining winding, the torque would be proportional to $1(60)^2 = 3{,}600$. Obviously, there is a vast amount of difference between these three quantities themselves and between them and a host of other conditions which may be set up involving various unequal distributions of restraining-coil currents. The problem is also complicated by the fact that the restraining elements themselves tend to saturate at the high currents in a reasonable relay design so that the torque per element departs from the square law at the high currents. This explains why it was found that while the relay characteristic could be bent quite sufficiently for the conditions of maximum restraint by simple saturation, the same bend in the curves did not apply for conditions giving minimum restraint.

A New Bus Differential Relay

The fact that either one, two, or three restraining circuits per relay might be energized, and thus cause the above variations, led to the development of the type *CA*-6 relay in which no less than two restraining elements could ever be energized regardless of variation in system connections or location of the fault (figure 8). The internal arrangement of the restraining circuits of this relay is shown in figure 6. It is this particular modification of the standard three-restraining-element ratio differential relay which gave the bent operating curves of figure 5. It may be seen from inspection of figure 6 that if current flows in only one of the restraining circuits of this relay, at least two of the restraining electromagnets are energized. This is accomplished by winding each of the restraining elements with two separate windings as shown in the diagram. Current flowing into one of the windings of the restraining element must also flow through the other winding of another restraining element. These windings have an equal number of turns so that they are equally effective.

The polarity marks shown indicate the respective ends of the two windings of a single element into which the currents must flow in order for their effect to be additive. That is to say, two currents of five amperes each flowing into the polarity ends of two windings on one element give the same effect as ten amperes flowing in only one of these windings. At the same time, if a current of five amperes flows in at the polarity mark of one winding and another in-phase current of five amperes flows in at the nonpolarity mark of the other winding on the same element, the net resulting effect is one of cancellation and no torque is produced.

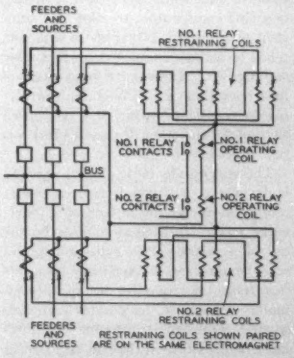

Figure 6. Differential protection using two CA-6 relays per phase with double restraining windings

Referring to figures 4 and 6 for the standard and special relays, respectively, and assuming a total of 50 amperes secondary for the external short-circuit current, this current may be divided in numerous ways between the circuits indicated. By assuming a torque proportional to the square of the current in each of the restraining windings for both the standard and the special relay, it will be found that there is considerably less variation in restraining torque between minimum and maximum conditions for the special relay than there is for the standard relay. This feature made it possible to follow the approach mentioned

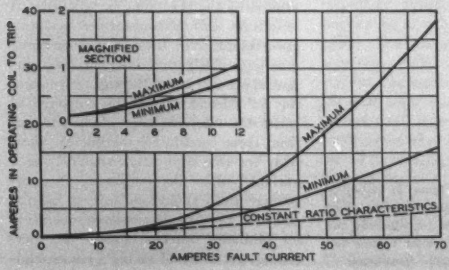

Figure 5. Operating characteristics of variable-ratio type CA-6 relay

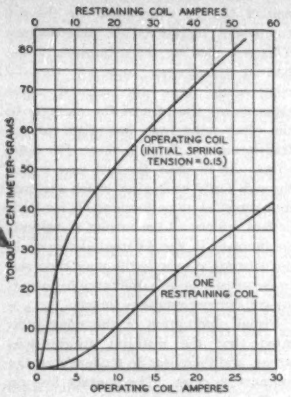

Figure 7. Torque-current curves of variable-ratio differential relay

previously which involved increasing the turns of the operating element to increase the sensitivity at low values of restraint current, and to obtain reduced sensitivity at the higher restraint currents by allowing the operating element to saturate. The reduction in variation between maximum and minimum conditions of restraint made possible a smaller variation between the operating curves at the higher restraint values, as shown on figure 5.

The torque curves shown in figure 7 indicate torque in centimeter-grams of the operating coil for various difference or operating currents and the torque per winding of each restraining element for various restraining currents. These torque curves may be used for constructing the operating characteristic of the relay for any particular division of restraining coil currents which may be chosen. Actually, in obtaining the operating curves shown, data were taken for seven different conditions intended to represent all possible divisions of a given fault current with respect to the restraining circuits and with respect to the direction in which this current might flow. It was found that test curves for any one of these conditions could be reproduced by calculated curves obtained by the use of the torque data of figure 7. Thus, the percentage ratio of the relay may be calculated for any given set of conditions. It will be found that the calculated ratio for any condition will fall between the limits indicated on figure 5.

The maximum condition of figure 5 is incurred when the fault current of indicated value flows in one restraining circuit only and flows out of the relay through the common connection to the other relay. The minimum condition shown represents two equal currents flowing into the relay in two restraint circuits and flowing out of the relay through the remaining restraint circuit without any current coming through the common connection to the other relay. In this case, the abscissa represents the total fault current, which is the sum of the two equal and smaller currents.

The time of operation of the relay may be as low as four cycles for internal faults based on one-fourth inch contact travel. A somewhat shorter operating time can be obtained with a correspondingly smaller contact separation.

System Tests

System Conditions

Tests on the relay, which has been described, were made under conditions similar to those that would exist if it

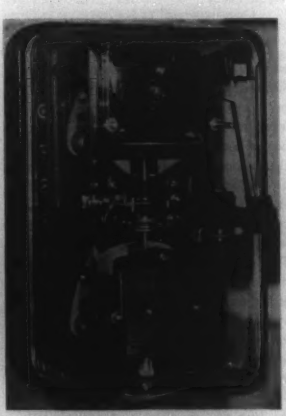

Figure 8. Type CA-6 relay

were installed to protect a 66-kv bus at a large generating station. Conditions simulated were as shown in figure 9 and consisted of five sources representing supply from four transformer banks and a bus-tie breaker, and four transmission lines. The current transformer for only one of these four lines was used, since it was assumed that a fault would exist on only one of the lines at a time. Maximum symmetrical currents for a feeder fault are shown, as well as the cross-sectional area of the current transformers in the various locations, and the manner of connecting them to the relay coils.

Test Setup and Test Procedure

Because of the extremely high fault currents (21,000 amperes at 66 kv) it was undesirable to make the tests under actual conditions. The method used is shown on figure 10 in which the current transformers, instead of operating on 66-kv current received 11-kv current, thereby reducing the necessary test current to one-sixth. The test current was further reduced by winding additional primary turns through the bushing-type current transformers. By this means, it was possible to so arrange the number of turns through the current transformers to correspond to the amount and division of fault current from the various sources involved, and at the same time keep the values of fault current well below the full-load rating of the equipment being used for tests. Reversing switches were used in the secondaries of the current transformers so that it was possible to represent both bus faults and through faults in various locations.

Figure 9 shows the bus setup, fault currents, and relay connections for one particular condition. By means of the switches mentioned above, and by varying primary turns in the current transformers, other operating conditions involving different bus connections, different magnitudes and distribution of fault current, and different fault locations were simulated.

Since the time required for the d-c component to decay is a function of the inductance and resistance of the circuit, it was necessary for the test circuit to have a time constant similar to that which would exist during actual fault condi-

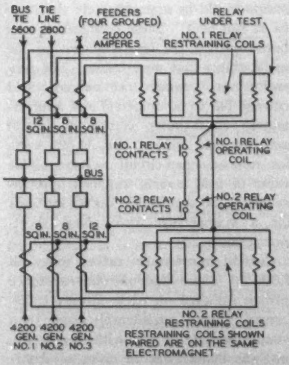

Figure 9. Approximate symmetrical fault currents from sources, and sizes of current transformers

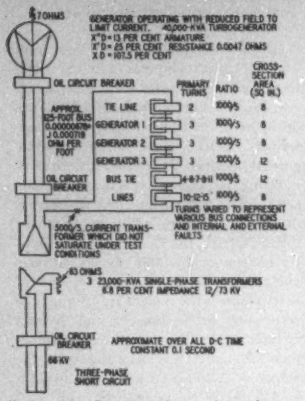

Figure 10. Diagram of current-transformer test circuit

tions. Constants of the test circuit as well as the current transformers used with their approximate cross section of iron, and their turn ratios, are shown on figure 10. The d-c time constant of the circuit was approximately 0.10 second.

The question was raised as to whether the time constants of the generator operating at reduced field would be the same as when operating at normal field. Conclusions were that neither the position of the field rheostat nor the value of the field current would affect the d-c time constant. The a-c time constants would be somewhat affected by the position of the field rheostat. However, by lowering the field current by reducing the voltage of the exciter and leaving the field rheostat in the position corresponding to full-load voltage, the time constants would be approximately the same as at full field. These conclusions were borne out by the results shown on the oscillograms that were taken. The generator was operated at reduced field current (40 to 50 amperes) and approximately 2,500 volts, compared to 230 amperes field current and 11,500 volts for no-load open-circuit voltage. This value of field current supplied approximately 1,400 amperes in the 12-kv leads for a symmetrical three-phase short-circuit fault.

Current-transformer ratios were all 1,000/5. There was a one-ohm resistance burden imposed on each current transformer. This is considerably larger than would normally be met with in practice, but was made large in order to determine, if possible, the limitations of this relay.

A total of 32 faults were applied. This was done by first closing the 12-kv oil circuit breaker, thus energizing the transformer bank, and then closing the 66-kv oil circuit breaker.

Oscillograph records were taken of the currents in the relay coils, as well as the exchange of currents between the two relays. During the tests only one relay was in use, the second relay being represented by dummy coils. Figure 11 shows an oscillogram taken during an asymmetrical through fault; figure 12, a symmetrical through fault; and figure 13 an asymmetrical inside fault.

As observed by the reference to figure 10 the tests were made on a single-phase basis. In order to make sure that the worst asymmetrical or symmetrical condition, whichever was desired, was obtained, it was necessary to make a number of tests under each fault condition. It was found from the oscillograph films that by making four to five tests, there was good probability of the fault current in one of these tests being completely offset.

Results

Figure 11 shows the oscillographic record of a test made under conditions simulating the operating conditions shown on figure 9. The latter figure shows the location of the fault, as well as the number of sources connected to the bus, and the amount and direction of the current flowing in the various current transformers. It will be observed that the primary current wave, figure 11, is completely offset, indicating maximum d-c transient. This wave represents a faithful reproduction of both the a-c and d-c components of the primary current, and was obtained by the use of a high-ratio current transformer shown on figure 10, which did not saturate on the current values used. It will also be observed that the current waves from the current transformers in the bus tie, tie line, and outgoing line circuits are not faithful reproductions of the primary current. It is obvious that neither the d-c component nor the a-c component represents the true values. This is caused by the saturation of the current transformer cores by the d-c component. Also, the current wave representing the sum of the currents to the other relay from the other current transformers of figure 9 shows the same effect. In all cases, the first peak comes through fairly well, after which the current-transformer performance is far from perfect. Since all the current transformers involved in the differential circuit do not saturate at exactly the same time, nor to the same degree, a difference or operating-coil current results as shown.

Visual observation of the relay indicated that the restraint torque was strong, and there was no tendency for the contacts to close. The contact line on the film, occupying the zero position of the primary current wave, also shows that the contacts did not close. (Closure of the contacts would have deflected this line, as shown on the films representing internal faults.)

Figure 12 shows another test made under exactly the same conditions as for figure 11, except that in this case an almost symmetrical current was obtained. The small amount of d-c component that was present, however, is responsible for the appearance in the operating-coil circuit of the current shown. The magnitude of this current is considerably less than the first peaks shown on the preceding figure, the calibration of the oscillograph element being unchanged. As before, the relay did not operate, but showed a trong restraint torque. In this case, the magnitude of the first cycle of the a-c component of the fault current was measured from the film and found to be approximately 25,600 amperes root-mean-square. From the standpoint of a-c saturation, this test was more severe than the preceding one because of the higher current values, yet it is readily noted that the performance of the various current transformers was much improved.

Figure 11. Oscillogram for an external asymmetrical fault

The answer to this is, of course, that in figure 12, the test current transformers are not performing under so severe a handicap imposed by d-c saturation.

A total of 20 tests were made representing through faults under various system conditions and for other magnitudes and distribution of fault current. Both asymmetrical and symmetrical currents were obtained, and, in all cases, the relay showed a strong restraining torque.

Figure 13 shows an oscillogram for a test representing an internal fault on the bus for which the relay should trip. For this test, most of the sources were considered to be on the other bus, so that the bus-tie circuit contributed 19,800 amperes and generator number 3 contributed 7,200 amperes to the 27,000-ampere fault.

As in figure 11, the effect of the d-c component in causing saturation is immediately obvious. The value of the operating coil current is reduced very materially from the theoretical value, but, by the same token, the restraint-coil currents are also reduced, and positive operation of the relay in a fraction over four cycles is shown. (The jagged contact line shown results from a very small current being used in the contact circuit for the operation of the oscillograph element.)

A total of 12 tests were made representing internal faults under various other system conditions. Both symmetrical and asymmetrical currents were obtained, and, in all cases, the relay operated to close its contacts in a positive manner.

Figure 13. Oscillogram for an internal asymmetrical fault

Conclusions

1. In applying bus differential protection, each application must be considered carefully with respect to the amount and distribution of fault currents, sizes and ratio of current transformers, number of generating sources, and, consequently, the number of restraining coils needed, relationship of protected bus to power sources as affecting the amount and extent of the d-c component, and other important factors.

2. The use of two or more standard percentage differential relays connected in series as shown in figure 4 makes available the number of restraining coils necessary for most applications.

3. In those cases where a ratio of maximum through fault current to minimum inside fault current is large due to high neutral impedance, relays with special characteristics as described in the paper are available.

4. System tests which simulate the conditions actually obtaining in practice demonstrated the reliability of the scheme and the relay described in the paper.

References

1. Current Transformer Excitation Under Transient Conditions, **D. E. Marshall** and **P. O. Langguth.** AIEE Transactions, volume 48, 1929, page 1464.

2. Relay Protection for Station Busses, **W. A. Lewis** and **R. M. Smith.** *The Electric Journal*, November 1937.

Discussion

C. D. Hayward (General Electric Company, Philadelphia, Pa.): In this paper the authors have described some of the special problems encountered in the application of differential relays to generator bus protection, as distinguished from transmission line bus or distribution bus protection. Briefly speaking these problems may be summarized under two heads as to causes:

First, in old installations it is usually found that the only current transformers already available in the feeder circuits are ones of low ratio. In case of a feeder fault close to the bus these are subjected to currents of many times their rating with the result that a high degree of saturation and consequent breakdown in ratio occurs. In the tests described in this paper the authors have confined their investigations to 1,000/5-ampere current transformers, but more often in practice ratios of 400/5 or 300/5 are found. It is evident that much higher degrees of saturation and consequent greater difficulty in applying a relay of the ratio differential type would have been experienced had current transformers of lower ratio been used. It is highly desirable, of course, from a cost point of view to use the existing current transformers if possible, rather than to install new ones or to rewind the old ones for higher ratio.

The second special problem is that of the long time constant of the d-c component of the current to a fault near the generators, for which the L/R ratio is higher than for a transmission line. It is well known to relay engineers that the steady-state ratio and wave-form breakdown of current transformers on overcurrent is greatly affected by the magnitude of the secondary burden. It is not so widely appreciated that the fidelity of current-transformer response to transient offset primary-current waves is also affected by the burden imposed. The d-c component of the primary wave induces a pulse of direct current in the secondary having a magnitude and rate of decay depending on the secondary burden. By the laws of electromagnetic induction the ampere-turns of the secondary d-c pulse oppose the ampere-turns of the primary d-c component and d-c saturation of the core is produced by their difference. The effect of the secondary pulse is always smaller and more rapidly decaying than that of the primary but approaches it most closely when the secondary burden is a minimum. Hence to reduce d-c saturation as well as to reduce a-c saturation and their effects on the current-transformer secondary-current response it is desirable to keep the burden applied to the current transformers as low as possible.

A year ago at this convention L. F. Kennedy and I presented a paper titled "Harmonic Current Restrained Relays for Differential Protection" which was later published in Electrical Engineering for

Figure 12. Oscillogram for an external symmetrical fault

May 1938. This paper describes a relay employing filter circuits to separate the harmonic and d-c pulse components of the current presented to it from the fundamental line frequency component, using the fundamental component to energize the operating coil and the harmonic and d-c pulse components to energize the restraining coil. By proper adjustment of the per cent harmonic restraint this relay is made to distinguish between differential currents due to internal faults which contain relatively low percentages of harmonics and those due to current transformer saturation on heavy through faults which contain relatively high percentages of harmonics. This relay is connected in the simple form of differential circuit shown in figure 1 of the present paper.

With this circuit the current-transformer secondaries may be connected directly to paralleling busses in the switchyard resulting in the minimum current transformer burden. Only four wires need be run from the switchyard busses to the relay panel for a three-phase relay setup including ground relays regardless of the number of bus circuits involved.

Compare this with the more complicated circuit for the ratio differential relay in figure 4 or 6. Here a minimum of 19 wires is required for a three-phase setup with only six circuits. Aside from the cost of installing and maintaining the extra wires they are undesirable because of the additional burden which they, together with the relay restraint coils, place on the current transformers.

While high-speed operation may not be absolutely necessary in all generator bus applications it is never undesirable at least and there are many bus applications, transmission busses particularly, where high-speed operation is necessary for stability considerations. While the harmonic-restraint relay has an operating time in the neighborhood of one cycle, figure 13 shows over four cycles for the ratio differential relay. Considerable contact bouncing is also shown by the jagged trace of the contact vibrator. While this would not be serious if only one contact were in the circuit, since contact arcing would probably allow the current to continue to flow after the first contact, it might be serious when two or more contacts each on a separate relay, are connected in series. In this case the circuit is not completed when the contacts close and bounce open alternately but must await a time when all are closed at the same instant. This effect does not show up on the oscillogram because according to the test description, only one relay was actually connected in the circuit, the other being represented by dummy coils.

In conclusion, we believe that for the differential protections of busses as well as other equipment the many advantages of relays employing the harmonic restraint principle should be seriously considered.

W. A. Lewis (Cornell University, Ithaca, N. Y.): As discussed in the paper the effect of the d-c transient is the most important single problem in high-speed relaying. This was first forcibly realized in connection with the high-speed relays at Boulder Dam. The problem was given very careful study, for transformer and generator differential relays. It was found that it was relatively easy to predict the design of a current transformer which would not saturate on the d-c transient, but such designs were quite unreasonable to build in a great many cases. In typical cases it was found that the d-c transient has as much as 100 times the saturating effect of the corresponding symmetrical a-c component of the current, that is, 100 times as much flux is required to transform the d-c component accurately as to transform the a-c component. It is thus obvious that the ratio curves of current transformers taken on symmetrical current, even as high as 20 times normal, are entirely unsatisfactory for predicting the performance when the wave contains the maximum amount of d-c transient. In the case of Boulder Dam, the maximum symmetrical short-circuit currents on external faults were limited to three or four times the normal current, and in this case it was possible to obtain a solution by the use of special current transformers.

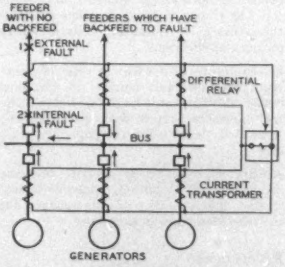

Figure 1. Schematic diagram of bus differential protection

However, suitable transformers were found to be four or five times as large as conventional transformers, and it was obvious that this method of procedure was entirely impracticable when the short-circuit currents or external faults are very much larger than the values encountered in this case.

It should, of course, be realized that the effect of the d-c transient is dependent to a large extent upon the rate of decay of the transient, or in other words upon the d-c time constant. This time constant is relatively long when the short circuit is near to high-capacity generating stations, but is reduced very rapidly as the resistance of the circuit is increased by the resistance of transmission circuits. Thus, danger from d-c transient effects is most pronounced in the immediate vicinity of large generating stations, and is almost nonexistent at distribution substations remote from the source of generation.

For any bus differential scheme to operate, it is essential that the current transformer carrying the fault current to an external fault be reasonably good. In the most extreme case, it may be visualized that a current transformer may saturate so severely that the secondary current is zero. When this is true, it is not possible to distinguish between an external fault and an internal fault, and no scheme of bus differential protection can possibly operate satisfactorily. This may be illustrated by reference to figure 1 of this discussion. Assuming first an external fault at the location marked 1 on the diagram, it will be seen that all the fault current must pass through the current transformer in the outgoing feeder. To simplify the problem, it has been assumed that there is no source of power at the other end of the feeder, so that no current will be fed back from the feeder into the fault. If it is assumed that the outgoing current transformer saturates completely, so that there is no secondary current, the current in the differential relay will be exactly the same as it would be for an internal fault at the location marked 2 on the diagram. Obviously, the relay should not trip for the external fault and should trip for the internal fault, so that satisfactory discrimination depends entirely upon the action of the current transformer in the feeder considered. It is thus obvious that the first consideration must be given to the current transformer, and the relay used must be designed to take the best advantage of the current-transformer characteristics. The authors of the paper have given very careful consideration to this problem, and have shown what can be done when each different condition is carefully considered.

Other schemes of bus differential protection which appear simpler have been proposed. However, as pointed out above, none of these can be successful if the current transformers are inadequate. In considering any scheme which makes use of departures of the wave form from a sine wave, it must be recognized that, at extremely high saturations, an iron-core current transformer approaches an air-core current transformer and, for such a case, the output current will again be very nearly sinusoidal, even though it is much less than the nominal ratio of the current transformer would indicate. In applying any such relay scheme, the characteristics of the output wave and the relay must be carefully analyzed, to make certain that the proper requirements for satisfactory operation are fully met.

It is obvious that the burden of the relay has an effect upon the operation of the protective scheme, and the smaller the burden the less the saturation will be in all the current transformers. However, it has been found that, in current transformers of ratios 2,000/5 and higher, the internal burden of the current transformer secondary winding is usually much greater than that of any of the relays proposed, and as a result the burden of the relay used is relatively unimportant in the determination of the current-transformer characteristics. Thus, while low burden is helpful, it becomes a matter of relatively small importance where the current transformer ratio is high, and therefore the desirable relay characteristics should not be sacrificed in an effort to make the burden extremely small. On the other hand, where the current-transformer ratios are 1,000/5 and lower, the internal burden of the current transformer is considerably smaller and more effort is justified in reducing the relay burden.

T. W. Trice (Consolidated Gas, Electric Light and Power Company of Baltimore, Md.): The authors of this paper are to be congratulated on the manner in which they thoroughly cover the major factors to be considered in bus differential protection. The way in which the conventional *CA*-4

relay has been modified is unique and its variable-ratio characteristics should make this relay particularly adaptable where there is considerable variation between minimum bus faults and maximum through faults.

Where the ratio of maximum through fault current to the minimum internal fault current is not large and two standard *CA*-4 relays could be used to cover all operating conditions, would it not be possible to use one of the modified relays connected as a simple ratio differential relay having six restraint windings?

It has been noted that the time of operation of the modified relay may be as low as four cycles based on one-fourth-inch contact separation and a somewhat shorter operating time can be obtained with a smaller contact separation. Assuming the smallest contact separation consistent with reliable performance approximately what would be the fastest operating time?

No mention is made as to whether or not any of these modified relays are in service. As in every case the final test of any piece of equipment is its actual service record and a summary of any operating experience with this modified relay would be of interest.

C. O. Werres (General Electric Company, Schenectady, N. Y.): Too much emphasis cannot be put on the fact that the success of differential protection is still very largely dependent upon current-transformer characteristics. This dependence is implied in the second paragraph of the article but it will bear reiteration.

The "faithful current transformer" mentioned is a most difficult but desirable goal. Its attainment involves building what has often been called the "ideal" transformer, that is, one with no errors, or to be more practical, negligible errors, throughout its entire range of performance. With this as a goal, much progress has been made. This, along with several other helpful measures listed below, is gradually improving the effectiveness and reliability of differential and naturally other types of protection:

(*a*). Improvements in current-transformer design.

(*b*). Determination of overcurrent characteristics of current transformers.

(*c*). Considering transformer characteristics when laying out protective equipments, etc.

(*d*). A trend toward lower ratio of fault current to current-transformer rating.

(*e*). Balancing burdens and keeping them at a minimum.

(*f*). Inserting resistance in the differential circuit.

Regarding current-transformer designs, the authors point out the difficulty of obtaining matched characteristics at high inductions from two transformers of the same design. The reason for this is obvious from *B-H* curves on core steels which show a wide spread between maximum and minimum characteristics of a given material. The safest solution then is to avoid saturation as was brought out in the Marshall-Langguth paper. However, in designing standard transformers, some compromise must be accepted as it is evident that nonsaturating transformers to meet every condition would be impracticable. A reasonable specification seems to be to limit the ratio error to five per cent at 20 times rated current with burden *Z*.

In view of proposals to adopt a ring-core construction as a means of approaching the ideal, it is pointed out that recent studies on various core designs show that for some ratings the rectangular core can be as good as, and more economical than, the ring core if the secondary is distributed over all four legs.

A. T. Sinks (General Electric Company, Lynn, Mass.): The authors are to be commended for again calling attention to some of the idiosyncrasies of current transformers and for emphasizing the fact that these phenomena must be considered carefully in differential relay applications. There are some points, however, with relation to their proposed ideal relay characteristic which are not quite clear.

The bushing current transformers used in the tests described in the paper had large cross sections of iron, so that the products of the iron cross sections and secondary turns were larger than would be normally encountered with instrument-type current transformers. Many current transformers in use on lower voltage systems will have large errors on asymmetrical current waves even for rather low currents. Therefore, the permissible sensitivity of the relay cannot be selected arbitrarily as it depends upon the faithfulness of reproduction of the fault currents by the current transformers, and particularly by the one that carries the total current to an external fault.

From the oscillograms of test and the authors' statement about four-cycle operation of the relay, it would appear that at least in some of the through-fault tests the only reason the relay did not operate was because it was not fast enough, as the oscillogram, figure 11 shows a large value of differential current for the first two cycles. With a given set of current transformers the period during which this false differential current may exist can be longer at low currents than at high ones. Consequently, the chances of this false differential current persisting long enough to operate the relay may be greater at lower values of primary current. Therefore, again why is a higher sensitivity at lower currents a desirable characteristic?

One of the questions which is frequently asked and apparently not well understood is: "Since the fault is fundamentally with the current transformers, why not build them to work right?" Some comment on this point, therefore, seems in order.

There are at least two ways of attacking this problem which give theoretically ideal results as follows:

1. Use air-cored current transformers with carefully balanced burdens, mutual inductances, and secondary-circuit constants.

2. Put enough iron and copper in the transformers to make them accurate up to the desired overcurrent.

There are, however, practical objections to either of these schemes. In the case of the first method, very careful balancing of the factors mentioned is absolutely essential, making each installation a hand-tailored job. Saturating burdens except in the differential element could not be tolerated. The transformers would be entirely special and would not be satisfactory for other services.

When an attempt is made to design a current transformer along conventional lines to reproduce asymmetrical waves faithfully, the first obstacle encountered is the enormous amount of core flux required to generate the d-c transient component of voltage in the secondary circuit. For instance, in the case of a 100 per cent offset wave, 0.1 second time constant, and 60 cycles frequency, the core flux required for the secondary IR voltage associated with the d-c transient is 37.7 times that required for the a-c component. (D-c flux/a-c flux $= 2\pi f \times$ time constant.) From this the large amount of iron necessary to take care of the d-c component of an asymmetrical wave can be readily appreciated. Nor does reducing the secondary-circuit resistance external to the transformer help beyond a certain point as the large amount of iron means a long length of secondary copper which can only be compensated for by making the cross section of copper large. This in turn requires more iron and so the quantities pyramid.

All this does not mean that it is impossible to design an iron-core transformer to reproduce accurately asymmetrical currents of high value, but it does mean that such a transformer will usually exceed acceptable limits of size and cost.

It would, therefore, seem that a relay of the harmonic-restraint type, which actually takes advantage of the peculiarities of the imperfect but economically feasible conventional transformer, is the most practical solution yet proposed.

J. A. Elzi (Commonwealth and Southern Corporation, Jackson, Mich.): This paper brings up the point that the application of relays for bus protection has not been given as much attention in recent years as transmission-line relaying. On the contrary, it is our opinion that bus protection has been given considerable attention but the factors that might cause incorrect operation, and which are very well discussed in this paper, have been recognized, and in many cases it has been found that the hazards involved outweigh the advantages to be gained. This paper and the results of tests contained therein show that these potential sources of incorrect operation are important and, in general, could not be taken care of with the relays available until recently.

The high-speed clearing of bus faults to minimize the damage done due to excessive fault currents is only one of the advantages to be gained. In some stations, it is equally as important to be able to sectionalize the bus in case of a fault so that there will be a minimum of loss of load and generating capacity. The extent to which this can be accomplished by a bus protective scheme is of course contingent on the arrangement of circuits on the bus and the number of sectionalizing points provided.

The results of the tests made with the new percentage differential relays described in this paper would seem to indicate that considerably more reliable operation could be expected from this relay than with some of the types heretofore available. The relatively small amount of current available in the differential circuit for the first few cycles in figure 13 leads to the question as to whether or not the relay would have operated in four cycles as indicated if this current had been further reduced by diversion to de-energized current transformers in parallel

with the ones which were supplying this current. It would also be interesting to know how the cross section of the cores of the current transformers used in this test compare with those of standard bushing-type current transformers usually supplied for this service voltage.

R. M. Smith and W. K. Sonnemann: The authors are gratified that the interest in this problem has brought forth interesting and construct.ve discussion.

J. A. Elzi contributes a valuable point when he asks if the relay would have operated in four cycles, as shown in figure 13, if the operating coil current had been further reduced by diversion to de-energized current transformers in parallel. The tendency is in this direction because of the fact that those current transformers not subject to current in their primaries will draw an excitation current in their secondaries depending upon the voltage across the operating coils of the relays and the magnetization curves of the current transformers involved. This voltage is distinctly limited, however, by the saturation characteristics of the operating coil circuit. Also, the "dead" current transformers, not being affected by d-c saturation, will be operating on their a-c magnetization characteristics and will draw only a very small amount of current. This phase of the problem should be considered if the number of feeder-circuit current transformers in parallel is very large, and if their ratio is low. The authors feel that the more important consideration of this point occurs when the relays must trip under normal load conditions when a light ground fault occurs on the bus. Under this condition the relay is much more sensitive, as illustrated in figure 5, so that more loss of operating-coil current to "dead" current transformers can be tolerated. Ample safety factor has been found in applications studied to date, but it is felt that this point must not be overlooked.

The cross section of iron in the test current transformers represent typical values for present-day 66-kv oil-circuit-breaker bushings, except that 12 square inches appears to be a little large. No definite standards have been established in this respect, however, so that considerable variation may be found.

Mr. Hayward mentions that the test conditions would have been more severe had lower-ratio current transformers been used, such as 400/5. It is admittedly true that, for a given primary current, and other conditions remaining the same, a lower-ratio current transformer will be likely to saturate more severely. This point has been admirably answered, however, in the discussion by W. A. Lewis in which he points out that reasonable performance must be had from the current transformer in the faulted feeder circuit in order that any type of relay may properly discriminate between an internal and an external fault. As a matter of fact, a relay of the ratio-differential type, having a slight time delay, is less likely to operate falsely with low-ratio current transformers than a relay of the high-speed (one cycle) type. This is because its time delay allows the badly saturated current transformer enough time to recover from d-c saturation sufficiently to discriminate between external and internal faults.

Mr. Hayward makes the point that it is well to keep the secondary burden as low as possible in order to minimize the effect of the d-c transient in saturating the current transformers. If this could be carried to the ultimate end so that no current transformer in any part of the circuit would saturate, then a simple differential relay as indicated in figure 1 would suffice. In the majority of cases, however, where the d-c transient has a long time constant, it will be found practically impossible to escape the effect of d-c saturation in those current transformers in the faulted feeder circuit, even by decreasing the lead burden, as has been pointed out. In this case, when saturation of the output current transformers is assured, it is a definite advantage to have some degree of saturation in the input current transformers as well. For example, in figure 11 of the paper, the traces show definite saturation of the various current transformers in the input leads to the bus. The degree to which the input current transformers fail to hold their ratio makes a corresponding reduction in the magnitude and duration of the differential current.

The statement made by Mr. Hayward that the relative percentage of harmonics present in the differential current is sufficient to discriminate between external and internal faults is somewhat optimistic, in view of the findings on a large number of tests. With sufficient time delay, a material percentage of harmonics will show up in the differential current for an external fault. If time delay is introduced, however, the relay is no longer a one-cycle relay. In figure 2 of this paper, for example, the first two cycles of differential current are obviously notably lacking in harmonics to any great degree. If the relay is sufficiently sensitive to harmonics to be adequately restrained from tripping for the first two cycles of the differential current of figure 2, then there is certainly grave doubt that the relay would trip properly when subject to the differential current wave form of figure 13 of the paper. It may be argued that the lower burden of the relay mentioned would do much toward improving the wave form of figure 13. This is quite true, but, on the other hand, the internal burden of the current transformers plus the burden of the differential circuit leads to the switchyard must still be considered. The experience of the authors is that there is practically an infinite variety of wave forms possible in the differential current, even when some of the variable factors are fixed. For example, the current-transformer characteristics and burden values will be fixed for a particular installation, but the variable location of the fault, involving a variable time constant, as well as variable current values, may be taken in an infinite number of combinations. Thus, it is impossible to say that any one particular wave form is typical of all external faults.

Attention has been called to the broken nature of the contact line of figure 13. It should be borne in mind that for these tests it was only desired to get a contact indication, and not to trip any breakers. The current through the contact circuit was extremely light, amounting only to that required to operate an oscillograph element, and was thus easily interrupted momentarily. Tests not described in the paper were made to establish the fact that two contacts in series could be made to pick up an auxiliary relay, at 125 volts direct current and four to five amperes, without additional delay, and were entirely successful. The auxiliary relay is necessary, of course, because of the large number of circuit breakers which must be tripped.

The supposition of Mr. Sinks that the only reason that the relay described in the paper did not trip for some of the external faults was because it was not fast enough is not correct. It is true that a large value of differential current existed for at least two cycles; however, a large restraining torque existed at the same time. The restraining torque was considerably in excess of the operating torque for all of the through faults.

Mr. Trice asks if one of the six-circuit special *CA*-4 relays might not be used in an application where two standard *CA*-4 relays would suffice. We interpret this question to mean that, since six restraining coils are available in the special relay, it would seem to be applicable on the basis of one relay per phase for a six-circuit bus. If applied in this way, however, each restraining element would receive current from two bus circuits. If a heavy current should flow into the bus in one of these circuits and away from the bus in the other, the ampere turns on that particular restraining element would be in opposition and thus cancel out. That is, equal and opposite heavy currents in the one restraining element would not produce restraining torque as they should. The same effect exactly would occur if the current transformers of the two paired circuits were paralleled on the secondary side and connected to one single-winding restraining element. In the first case, fluxes are paralleled. In the second case, currents are paralleled. The net effect is the same. These considerations indicate that if six restraining elements are required, then two relays per phase are necessary, whether they be the standard or the special type.

Some gain may be made in shortening the operating time for internal faults by decreasing the contact travel. However, not a great deal can be accomplished by this means. Probably the fastest operating time under most favorable conditions would be two to three cycles.

In answer to Mr. Trice's third question, no relays of the special type having double windings and variable-ratio characteristic have yet been placed in service, although some are now on order.

Copper-Oxide Modulators in Carrier Telephone Systems

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Synopsis: Copper-oxide modulators are widely used in telephone systems for translating either single speech channels or groups of speech channels to carrier-frequency locations on the lines. A number of simple circuit arrangements have been developed that enable suppression of certain undesired frequencies to a degree that is impractical in tube modulators. These modulators transmit equally well in either direction and the modulating elements are more nonlinear than in tube modulators. As a result numerous effects are found that ordinarily are not important in the tube arrangements. Analytical studies have been considerably simplified by the use of a small signal, and a large carrier controlling the impedance variation of the copper oxide. It is found in this case that the superposition and reciprocity theorems hold for all the circuits that it has been possible to analyze even though the modulator is made up of nonlinear elements. Open and short-circuit impedance measurements can be made use of as in four-terminal linear networks, and a generalized reflection theory developed. Performance data are given for an idealized modulator under a variety of operating conditions.

AT LEAST as early as 1927, copper-oxide rectifiers were being tried as modulators for the speech channels of carrier telephone systems in this country. At this time only a rather large type of rectifier was available, better adapted for power use rather than in modulating the few milliwatts of a speech signal. Largely because of instabilities these early units were found to be unsatisfactory for modulator use. Further developments in copper-oxide rectifiers made in various laboratories extended the variety and improved the quality of the product available, so that by about 1931 they began to be promising as serious competitors for vacuum tubes in modulators. Since 1931 continued improvements in copper-oxide rectifiers have rapidly increased their field of application until now they are employed in practically all modulators of the latest types of carrier telephone systems.

In the new systems a copper-oxide modulator is used instead of the previous push-pull arrangement of two vacuum tubes. In cable,* open-wire, and coaxial carrier systems, from 26 to 28 of these modulators are needed in each direction for translating each 12-channel group of speech bands from voice to carrier and back again. These copper-oxide modulators have no power costs, tube replacements, or possibilities of power failures. In figure 1 the four $^3/_{16}$-inch-diameter copper-oxide disks generally used in a carrier telephone modulator are shown individually, assembled with connections, and potted in a can.

The carrier terminals have tended to become increasingly complex as it became their function to place more and more channels on a single pair of wires. The extreme simplicity and reliability of copper-oxide modulators have been of great value in helping to overcome this tendency. Copper-oxide modulators have been used from zero frequency to nearly four million cycles. Certain modulators for coaxial carrier systems have been designed to modulate simultaneously as many as 60 speech channels spaced over a 240,000-cycle band of frequencies.

Copper-oxide modulators probably differ most from tube modulators because the simplicity of the rectifier elements allows a much greater variety of circuit arrangements to be used. Although the underlying principles of operation are not new, it has become necessary to investigate numerous transmission effects that could be neglected in tube modulators. This has resulted not only from the newer circuit arrangements with their smaller losses, but also from higher transmission standards for the over-all system along with the greatly increased numbers of modulators in long circuits. Copper-oxide modulators, unlike tube modulators, transmit signals equally well in either direction. While this is a simplification in allowing a modulator also to be used as a demodulator, the modulator becomes complicated by the effects of reflections back and forth into the signal bands of numerous frequency bands of modulation products.

Figure 1. Four-disk copper-oxide modulator

Circuit Arrangement

The circuit arrangements used in copper-oxide modulators generally are concerned either with carrier suppression, with carrier transmission along with the signal, or with balancing action to suppress certain unwanted bands of signal frequencies. In most carrier telephone systems economy of frequency space and amplifier load capacity demands the use of single-sideband carrier-suppressed transmission.

In figures 2*a*, 2*b*, and 2*c* three types of copper-oxide modulators are shown, each arranged to suppress the carrier in both the signal input and the signal output circuits. In figures 2*d* and 2*e* the carrier is balanced out in only one signal branch. In the usual arrangements a signal-band selective filter must be used in each signal branch to restrict transmission to that of the wanted frequency band. Largely in this way interferences are guarded against, not only into other channels or systems to which the modulator output circuit is connected on the line or at the distant

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* The general features of carrier telephone terminals have been described in a paper "Cable Carrier Telephone Terminals," by R. W. Chesnut, L. M. Ilgenfritz, and A. Kenner (ELECTRICAL ENGINEERING, January 1938).

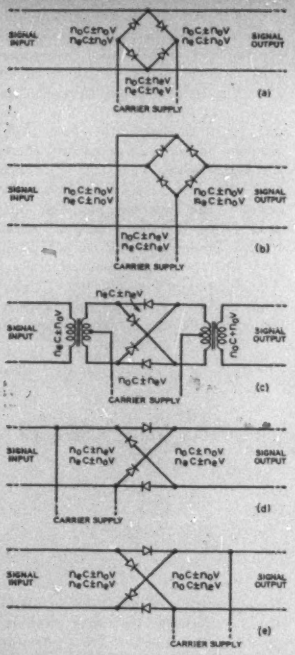


Figure 2 (left). Types of copper-oxide modulator circuits

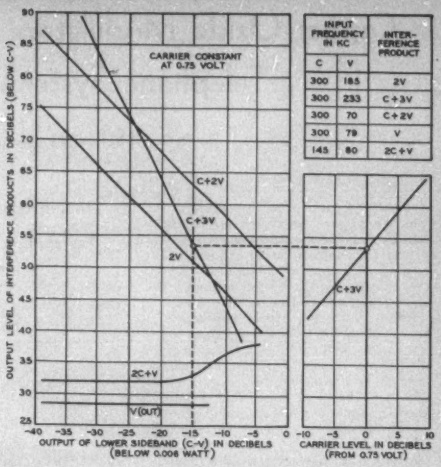


Figure 3. Intensity of modulation products in a representative double-balanced copper-oxide modulator

end, but also back into the complex array of facilities to which the input circuit may be connected.

In any of the circuits shown, modulation results from either the reduction or reversal of the current flow between the input and output signal circuits at periodic intervals as the carrier varies the copper-oxide resistance back and forth between high and low values. In figure 2*a* where the connections of the input and output signal circuits are periodically short-circuited by the carrier-actuated copper oxide, transmission of the modulated signal into the input circuit or the unmodulated signal into the output circuit is prevented by filters, each of high impedance at the frequency of the other signal. In figure 2*b* the connections between the signal and modulated signal circuits are open-circuited periodically by the carrier. In this case each filter should have a low impedance at the other signal frequency. In figures 2*c*, 2*d*, and 2*e* the copper-oxide rectifiers are made to become alternately low and high resistance in pairs as the polarity of the carrier is either in the same direction as the arrows or in the opposite direction. As a result current flow from the input signal circuit into the output is periodically reversed by provision of a periodically reversing low-impedance path. In effect each signal is balanced from the other's circuit.

Although an indefinite number of other circuit configurations can be used, no novel transmission feature would be found which was not present in the five circuits already shown. Third order modulators in which the copper oxide is arranged to give equal interruptions to the signal in both positive and negative half cycles of the carrier are exceptions not considered here. In addition, circuits like Hartley's, in which phase discriminations have been obtained in the sideband outputs from two modulators by altering both the carrier and signal input phase of one, can be viewed as composed of two modulators of any of the types illustrated.

In these copper-oxide modulators all modulation product frequencies can be grouped into four classes:

$$n_o c \pm n_o v$$
$$n_o c \pm n_e v$$
$$n_e c \pm n_o v$$
$$n_e c \pm n_e v$$

in which c and v are the carrier and input signal frequencies and n_o is any odd number 1, 3, 5, etc., while n_e is any even number 0, 2, 4, 6, etc. If c and v contain more than one frequency each, n_o and n_e are, respectively, the odd and even combinations of all multiples of the c and v frequencies. All frequencies of one of these four types appear together in a specific branch of the modulator circuit; and they will not appear in another branch unless from a dissymmetry among the copper-oxide units or unless inherent in the circuit configuration. The branches in which the modulation products appear are shown in the circuits illustrated. It is apparent that only in the case of the double-balanced circuit of figure 2*c*, are all of these types of products completely separated in different parts of the circuit. In the other circuits shown the classes of products appear together in combinations of two types. In any balanced circuit that can be drawn the above relationships will be found to hold.

Modulation products will be of a type to which the circuit offers some degree of balance, of a type that can be made to vary in importance relative to the signal by adjustment of either the carrier or signal voltage, or of a type to which neither balance nor level adjustment is of any benefit. Satisfactory operation of such modulators requires large carrier voltages relative to those of the signal, so that products like $c \pm v$, $2c \pm v$, $3c \pm v$, etc., tend to be of large magnitude while products like $c \pm 2v$, $c \pm 3v$, etc., tend to be small. Furthermore, the former types can be made to predominate even more over the latter types either by increasing the carrier amplitude or by decreasing the signal levels. A 6-decibel reduction in signal results in 12-decibel reduction of $c \pm 2v$ and 18-decibel reduction in $c \pm 3v$. In any circuit application interferences of this type lend themselves to reduction in so far as carrier power is available for high-signal-level operation, or in so far as noise does not limit for low signal levels. Laboratory measurements of some of these modulation products made during the development of a group modulator for a 12-chan-

nel open-wire carrier system are shown in figure 3 for a double-balanced modulator like that of figure 2c. Single $^3/_{16}$-inch-diameter disks as shown in figure 1 were used in each bridge arm. About 20 to 30 decibels reduction in interference by balance alone is quite readily obtained in the normal run of manufactured copper-oxide rectifier elements, for those products to which the circuit arrangement offers a balance. Any further improvement must be obtained either by closer control of manufacture or disk selection, by artificial balancing with some means such as capacitor-resistance potentiometers, or by statistical averaging through use of numbers of disks in each bridge arm.

In single-channel modulators interferences caused by the signal into its own signal band will occur only in the presence of the signal. In such cases they need be only 20 to 30 decibels below the signal, except in special cases, as for example, modulators for broad-band program channels. In multichannel systems interferences may be produced in the silent channels by the active channels. This kind of interference or crosstalk is ordinarily made to be 70 decibels or more below the wanted signals for commercial telephone service. In such cases overlapping bands of frequencies not improved by level adjustment are avoided by judicious choice of the carrier frequencies.

Circuit Impedance and Loss

In all modulators the carrier serves merely as a means for obtaining a simple periodic variation of the impedance presented to the signals. It is not only immaterial to the signals how this variation is obtained, but the signals also are totally unaware of whether electrical, mechanical, or other means are used, just so long as the signals themselves are unable to affect the time variation of this impedance. In a copper-oxide modulator, only by making the carrier amplitude large compared to the signal amplitudes across the rectifier elements, can the impedance of the rectifiers be made to vary at carrier rather than signal rates. Too large a signal amplitude not only results in the production of undesired frequencies, but also the impedance and loss characteristics of the modulator vary with the signal amplitude. With small signals the carrier energy is used up in maintaining the copper oxide at prescribed impedance values at each instant of time, and none of the modulation products involving the signal receive more than a negligible amount of energy from the carrier. As a result the output signal energy will always be less than that of the input signal, partly because of i^2r losses within the copper oxide, and partly from the diversion of the input signal energy into the energies of the many modulation-product frequencies.

The signal impedance of a copper-oxide modulator is a combination of a characteristic impedance of the rectifier elements and the impedance of the connected circuits at all the modulation-product frequencies. The characteristic impedance of the rectifier can be viewed crudely as an average of the impedance encountered by a small signal over a cycle of the carrier, treating each instantaneous value of the carrier voltage as a d-c bias. If the impedance for small superimposed alternating voltages is measured on a single copper-oxide disk at various direct bias voltages, this impedance generally changes with both bias and frequency. Measurements to 200 kilocycles made on a $^3/_{16}$-inch-diameter disk are shown in figure 4. At all negative bias voltages the impedance is a resistance in parallel with a capacitor. This resistance decreases rapidly with increasing frequency while the shunt ca-

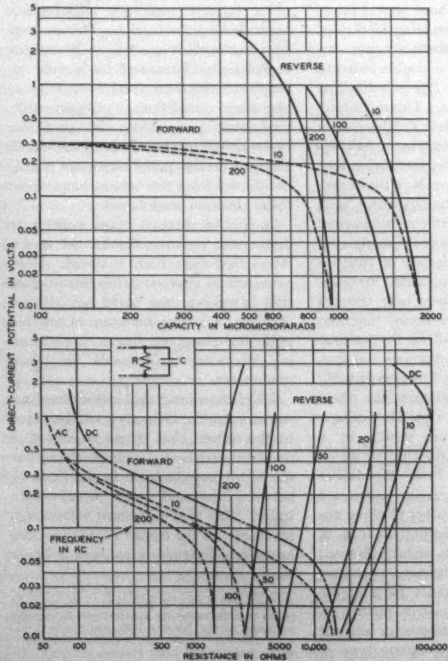
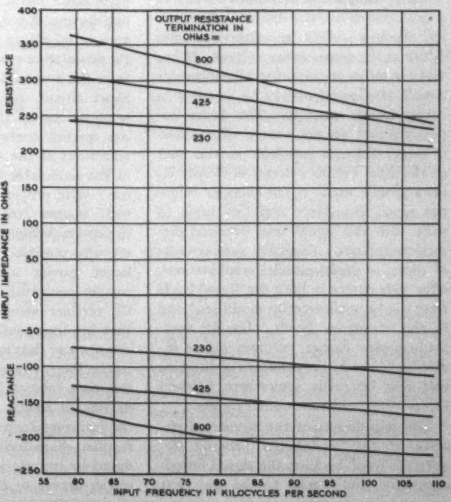


Figure 4. Impedance of a copper-oxide disk at various forward and reverse direct voltages for small superposed alternating voltage

Figure 5. Impedance of a representative double-balanced modulator



pacity decreases only a moderate amount. At moderate positive voltages (about one-half volt) the impedance becomes resistive and does not change appreciably with frequency. Experimentally it is found that the signal impedances in resistance-terminated modulators can be made largely free of reactance at high frequencies by using either large carrier amplitudes, inductive tuning of the copper-oxide capacities, or lower-impedance-connected signal circuits to accentuate the importance of the low-resistance part of the copper-oxide characteristic. Very much lower circuit impedances must be used at the higher frequencies. Where 600 to 1,000 ohms is a satisfactory impedance at speech frequencies, less than 50 ohms may be the best impedance to use, at three megacycles.

Impedance measurements on a double-balanced modulator designed to translate a 12-channel group of frequencies for cable carrier systems from a band at 60 to 108 kilocycles to a 12- to 60-kilocycle band are shown in figure 5 for several resistance terminations. Absence of any impedance irregularities with frequency is apparent. Also, the tendency is shown for the modulator impedance to become less reactive with lower-resistance terminations.

Inasmuch as copper-oxide disks are available in sizes from $^1/_{16}$ inch to more than an inch in diameter, a wide range of circuit impedances is possible varying from only a few ohms to thousands of ohms Large-area disks roughly are equivalent to small-area disks in parallel. Thus by using a disk of n times the area of a small one or n of the small ones in parallel, the best circuit impedance becomes $1/n$th at the same carrier voltage. Either disks in series or ones of smaller diameter enable the impedance to be raised in a corresponding manner. The lower impedance and greater energy dissipations of larger disks, or paralleled smaller ones at the same carrier voltage, obviously allows greater input signal energies before the signal impedance and loss begin to vary with the signal, and overload distortion appears. Similarly series stacks of disks, or series-parallel combinations, offer wide choice in both the signal levels that can be satisfactorily modulated and in the impedance levels. Usually root-mean-square carrier voltages across individual disks in the conducting direction will best be made somewhere between three-tenths and three-fourths volts.

The impedances of the connected circuits at the modulation product frequencies react back on the signal impedances in a way similar to the way that the two terminating impedances of a four-terminal linear network react on each other. In the case of the copper-oxide modulator a reaction from some modulation product back into the signal impedance is less and less as the product becomes of higher order, or as the circuit loss to it becomes greater. Where the impedances of the connected circuits have bothersome interactions with the copper-oxide impedance either at the signal frequencies or the lower-loss modulation products, resistance-pad separation is usually the simplest solution if the increased loss can be tolerated.

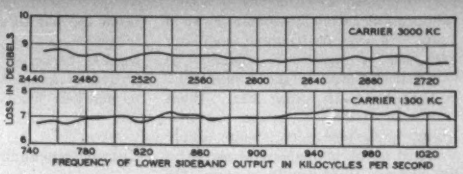


Figure 6. Loss in a double-balanced group modulator for coaxial systems

Energy losses in copper-oxide modulators between signal input and single-sideband signal output have been found to be no greater than eight or nine decibels even at frequencies of three or four megacycles. At lower frequencies five- or six-decibel losses are normal, but losses as low as two decibels have been obtained under less practical operating conditions. Experimental loss measurements are shown in figure 6 for a double-balanced modulator using single $^3/_{16}$-inch-diameter disks in each bridge arm. This modulator was designed to modulate simultaneously 60 speech channels occupying a 240,000-cycle band width. The modulator loss, like the impedance, depends on the impedance terminations of the modulator at all the modulation-product frequencies as well as on the internal losses of the modulator. Short circuit, open circuit, or reactive terminations at the unwanted frequencies, permit energy losses only through reflections at the signal-circuit junctions to the modulator or within the modulator. With proper terminations and loss-free copper oxide, 100-per-cent-efficiency frequency translations are theoretically possible. In a practical case, a larger carrier amplitude results in a smaller percentage of the time in which the rectifier elements have impedances that are comparable to the connected circuits and that are neither blocking nor conducting. Signal energies are lost in this time interval, so a higher efficiency modulator results. The time spent on the intermediate resistance parts of the rectifier characteristic can be further reduced by introducing harmonics into the carrier wave, so that a square type of wave results. The resistance of the rectifier is abruptly switched back and forth between blocking and conducting values in this manner. When the connected circuit impedances at the unwanted frequencies are very high or low, best efficiencies result when transmission between the signal circuits is blocked most of the time. Thus in a circuit like that of figure 2*a* when the filters are high impedance at the unwanted products, highest efficiency results when the copper oxide is a low-resistance short circuit for the major portion of the carrier cycle. In figure 2*b* an open circuit is desirable most of the time.

Linear Modulator Theory

The analytical studies that have been of most benefit in the development of copper-oxide modulators have made use of a variable resistance characteristic controlled by the carrier. This assumption has made it possible to investigate modulator performance* for a wide variety of characteristics under a great many operating conditions. Copper-oxide-modulator performance in particular cases as well as the effects of the circuit elements on this performance can readily be inferred from the data at hand about these idealized modulators.

In limited space it is not possible to discuss the varieties of resistance modulators that have been analyzed. However, certain viewpoints will be discussed that have been very useful not only for obtaining solutions for some of the hypothetical cases, but also in supplementing laboratory experiments on actual modulators.

All of these analytical studies have assumed a signal sufficiently small compared to the carrier, that it can be varied in magnitude without noticeable changes in the signal impedance or in the linearity between input and output signal amplitudes. This is in agreement with design procedure, as the circuit impedances and losses are determined on such a linear basis.

* A physical picture of modulator performance in terms of linear networks is developed in a paper published in the January 1939 *Bell System Technical Journal:* "Equivalent Modulator Circuits," by E. Peterson and L. W. Hussey.

Superposition Principle

All of the modulator circuits with which we have been dealing, though composed of nonlinear elements, have been resolved into the equivalent of linear systems by virtue of using a large carrier and small signal amplitude. We may simultaneously apply any number of signal frequencies, but all have negligible effect on the periodic changing of the nonlinear element resistance by the carrier. These frequencies may be modulation product voltages, some applied at the output terminals and some at the input terminals, but in all cases, even though frequencies may coincide, it can be shown that the principle of superposition will hold without interaction between the applied forces and the responses. This permits a great simplification in the mathematical approach to modulator analysis, because the modulation product or signal voltages can be applied one at a time and the current responses summed. The voltage-current ratios at each frequency can then be replaced by equivalent impedances.

Any nonlinear resistance like copper oxide will have a current-voltage characteristic that can be expressed as accurately as desired by

$$i = a_1 e + a_2 e^2 + \ldots a_n e^n \qquad (1)$$

If a carrier and signal voltage are applied to this nonlinear element, each term beyond the first will independently produce currents of new frequencies composed of the intermodulation products of these two voltages. If in turn the external impedances at these new frequencies are not zero, new voltages will appear across the nonlinear element to produce still more new frequencies. In this case the simplest consideration is to minimize the number of voltages by presenting zero impedance to the modulation products. If the carrier voltage is $C \cos ct$ and the input signal voltage $S \cos st$, the current flow in the nth term is

$$i = a_n (C \cos ct + S \cos st)^n \qquad (2)$$

In the binomial expansion of this expression it is obvious that linear response to the signal and freedom from distortion result when the ratio of carrier to signal is made sufficiently large so that only the first two terms are important.

$$i \approx a_n[(C \cos ct)^n + n(C \cos ct)^{n-1} S \cos st] \qquad (3)$$

The first term in equation 3 is the current flow at direct current and harmonics of the carrier; it has no effect on the input signal and output signal except in so far as impedance termination presented across the nonlinear element at the carrier harmonic frequencies may alter the carrier-voltage harmonic content. The signal input current and the signal output current, as well as the unwanted modulation products of the signal, result from the second term. The even values of n produce the even-order sidebands, second order being the output signal, while the odd values of n produce the input signal current and the odd-order sidebands. These currents can be evaluated from

$$\cos^n b = \frac{K^n_{\frac{n}{2}}}{2^n} + \sum_{m=1}^{m=n} \frac{K^n_{\frac{n-m}{2}}}{2^{n-1}} \cos mb$$

in which $K^n_{\frac{n-m}{2}}$ is equal to the combination of n things taken $\frac{n-m}{2}$ at a time for $\frac{n-m}{2}$ integral and is equal to zero for $\frac{n-m}{2}$ nonintegral. The signal input current is

$$i_s = \frac{a_n n K^{n-1}_{\frac{n-1}{2}}}{2^{n-1}} C^{n-1} S \cos st \qquad (4)$$

while the second-order output signal sideband is

$$i_{c \pm s} = \frac{a_n n K^{n-1}_{\frac{n-2}{2}}}{2^{n-1}} C^{n-1} S \cos (c \pm s)t \qquad (5)$$

Similarly, if the output signal voltage at second-order sideband frequency $(c \pm s)$ had been applied along with the carrier in place of the input signal, and of an equal amplitude, then the following currents of the output and input signal frequencies would result

$$i_{c \pm s} = \frac{a_n n K^{n-1}_{\frac{n-1}{2}}}{2^{n-1}} C^{n-1} S \cos (c \pm s)t \qquad (6)$$

$$i_s = \frac{a_n n K^{n-1}_{\frac{n-1}{2}}}{2^{n-1}} C^{n-1} S \cos st \qquad (7)$$

If both signal input and output frequency voltages are applied simultaneously, equation 3 then becomes

$$i \approx a_n[(C \cos ct)^n + n(C \cos ct)^{n-1} \cdot S \cos st + n(C \cos ct)^{n-1} \cdot S \cos (c \pm s)t] \qquad (8)$$

The current responses obviously are the sum of the separate responses from independent application of the two frequencies. Even if a complex array of terminating impedances are supplied so that voltages appear across the nonlinear element at all the modulation product frequencies, each new voltage will individually produce its own current response, quite independently of the responses that are being produced by the other voltages. It can readily be seen then that superposition does not depend on any assumptions about what the terminating impedances may be.

Reciprocal Theorem

Equations 5 and 7 show that the sideband response to an input signal voltage is exactly equal in magnitude to the input signal response to the same amplitude sideband voltage. It can readily be seen that any two modulation products also bear such a reciprocal relationship between their voltages and currents, as a result of using the same amplitude and frequency of carrier harmonic multiplier of their respective voltages to modulate between the two frequency positions. Although reciprocity has been proved valid here only for short-circuit terminations at the modulation-product frequencies, it can also be proved under numerous other conditions of circuit operation. It seems that, regardless of modulator complexity of impedance terminations or frequency loss effects, *the reciprocal theorem is a necessary attribute of such a linear and bilateral system in which there are no internal energy sources.* Two-way systems in which an amplifier for example, is included as an internal energy source in one or both directions will, of course, violate the reciprocal theorem if the gains in the two directions are different. This arrangement is, however, both bilateral and linear.

Complete Performance Criteria

The laws for transmission between a signal input frequency and a signal output frequency can be completely specified from open- and short-circuit impedance measurements at the signal input and output frequencies, regardless of the complexity of the modulator. (From such measurements optimum impedance terminations can even be determined for linear-bilateral systems with internal energy sources.)

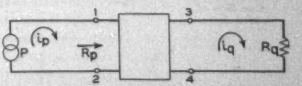


Figure 7. Four-terminal network equivalent of a linear modulator

The four-terminal network of figure 7 is assumed to represent a modulator with a large carrier amplitude and having small signal voltage P of frequency p applied at

the input terminals 1–2 at the left. Current of the output signal frequency q flows out of the terminals 3–4 into the impedance R_q. The generator P is assumed to have zero internal impedance at its own frequency. Impedance terminations at the 1–2 and 3–4 terminals at all other modulation-product frequencies are perfectly general; whatever they are in a particular case, it is assumed that they are undisturbed as the terminations of the input and output at the signal frequencies are varied between open circuit and short circuit. The following symbols are used for the impedances looking into the modulator at the input terminals at input signal frequency p and at the output terminals at signal output frequency q.

Z_{po} = impedance at p for open circuit at q
Z_{qo} = impedance at q for open circuit at p
Z_{ps} = impedance at p for short circuit at q
Z_{qs} = impedance at q for short circuit at p
R_q = impedance termination at frequency q
R_p = impedance of modulator at frequency p with R_q at 3–4 terminals for frequency q
K_a = transfer admittance between voltage at frequency p applied at the 1–2 terminals and short-circuit current at frequency q flowing from 3–4 terminals
K_b = transfer admittance between voltage applied at 3–4 terminals at frequency q and short-circuit current at frequency p flowing from 1–2 terminals

For R_q first short-circuited.

$$i_{q1} = PK_a \tag{9}$$

$$i_{p1} = \frac{P}{Z_{ps}} \tag{10}$$

If the short circuit on R_q is removed, the following two additional currents will flow due to superposition of a new voltage $-i_qR_q$

$$i_{q2} = \frac{-i_qR_q}{Z_{qs}} \tag{11}$$

and

$$i_{p2} = -i_qR_qK_b \tag{12}$$

$$i_q = i_{q1} + i_{q2} = \frac{PK_a}{1 + \frac{R_q}{Z_{qs}}} \tag{13}$$

$$i_p = i_{p1} + i_{p2} = \frac{P}{Z_{ps}} - \frac{PK_aK_bR_q}{1 + \frac{R_q}{Z_{qs}}} \tag{14}$$

The efficiency of the frequency translation, measured by the ratio of the power delivered to R_q to the power into terminals 1–2, is

$$\eta = \frac{i_q^2R_q}{i_pP} = \frac{\left(\frac{K_a}{1 + \frac{R_q}{Z_{qs}}}\right)^2 R_q}{\frac{1}{Z_{ps}} - \frac{K_aK_bR_q}{1 + \frac{R_q}{Z_{qs}}}} \tag{15}$$

which is maximum for

$$R_q = \frac{Z_{qs}}{\sqrt{1 - K_aK_bZ_{ps}Z_{qs}}} \tag{16}$$

The maximum efficiency is then

$$\eta_{max} = \frac{K_a^2Z_{ps}Z_{qs}}{(1 + \sqrt{1 - K_aK_bZ_{ps}Z_{qs}})^2} \tag{17}$$

Table I. Correspondence Between Currents Entering and Leaving a Reversing-Switch Modulator

Component on One Side of Modulator	Corresponding Components on Other Side of the Modulator			
	$\frac{2k^*}{\pi}$	$\frac{2k}{3\pi}$	$\frac{2k}{5\pi}$	$\frac{2k}{7\pi}$
I_0	I_{1-} I_{1+}	I_{3-} I_{3+}	I_{5-} I_{5+}	I_{7-} I_{7+}
I_{1-}	I_0 I_{2-}	I_{2+} I_{4-}	I_{4+} I_{6-}	I_{6+} I_{8-}
I_{1+}	I_0 I_{2+}	I_{2-} I_{4+}	I_{4-} I_{6+}	I_{6-} I_{8+}
I_{2-}	I_{1-} I_{3-}	I_{1+} I_{5-}	I_{3+} I_{7-}	I_{5+} I_{9-}
I_{2+}	I_{1+} I_{3+}	I_{1-} I_{5+}	I_{3-} I_{7+}	I_{5-} I_{9+}
I_{3-}	I_{2-} I_{4-}	I_0 I_{6-}	I_{2+} I_{8-}	I_{4+} I_{10-}
I_{3+}	I_{2+} I_{4+}	I_0 I_{6+}	I_{2-} I_{8+}	I_{4-} I_{10+}
I_{4-}	I_{3-} I_{5-}	I_{1-} I_{7-}	I_{1+} I_{9-}	I_{3+} I_{11-}
I_{4+}	I_{3+} I_{5+}	I_{1+} I_{7+}	I_{1-} I_{9+}	I_{3-} I_{11+}
I_{5-}	I_{4-} I_{6-}	I_{3-} I_{8-}	I_0 I_{10-}	I_{2+} I_{12-}
I_{5+}	I_{4+} I_{6+}	I_{3+} I_{8+}	I_0 I_{10+}	I_{2-} I_{12+}
I_{6-}	I_{5-} I_{7-}	I_{4-} I_{9-}	I_{1-} I_{11-}	I_{1+} I_{13-}
I_{6+}	I_{5+} I_{7+}	I_{4+} I_{9+}	I_{1+} I_{11+}	I_{1-} I_{13+}
I_{7-}	I_{6-} I_{8-}	I_{5-} I_{10-}	I_{3-} I_{12-}	I_0 I_{14-}
I_{7+}	I_{6+} I_{8+}	I_{5+} I_{10+}	I_{3+} I_{12+}	I_0 I_{14+}
I_{8-}	I_{7-} I_{9-}	I_{6-} I_{11-}	I_{5-} I_{13-}	I_{4+} I_{15-}

NOTE: A current of the frequency indicated in the first column will be modulated to produce the components written on the same line, the magnitudes of which are the magnitude of the generating current multiplied by the factors at the top of the columns.

$$^*k = \left(\sqrt{\frac{R_r}{R_f}} - 1\right) \Big/ \left(\sqrt{\frac{R_r}{R_f}} + 1\right)$$

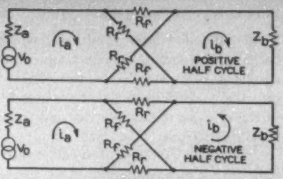


Figure 8. Equivalent circuit of a double-balanced modulator

When equation 16 is substituted in (14) it is found that

$$R_p = \frac{P}{i_p} = \frac{Z_{ps}}{\sqrt{1 - K_aK_bZ_{ps}Z_{qs}}} \tag{18}$$

In order to evaluate K_aK_b, open-circuit impedance measurements must also be made. By superposition methods like those used in obtaining equations 11 and 12 it can readily be shown that

$$\frac{1}{Z_{po}} = \frac{1}{Z_{ps}} - K_aK_bZ_{qs} \tag{19}$$

$$\frac{1}{Z_{qo}} = \frac{1}{Z_{qs}} - K_aK_bZ_{ps} \tag{20}$$

From these two equations, it follows that

$$\frac{Z_{ps}}{Z_{po}} = \frac{Z_{qs}}{Z_{qo}} \tag{21}$$

$$K_aK_b = \frac{\frac{1}{Z_{ps}} - \frac{1}{Z_{po}}}{Z_{qs}} \tag{22}$$

and K_aK_b can be determined from any three of the open-short measurements by using (21) and (22). It follows that

$$K_aK_bZ_{ps}Z_{qs} = 1 - \frac{Z_{ps}}{Z_{po}} \tag{23}$$

Upon substitution in (16) and (18) it is found that

$$R_q = \sqrt{Z_{qo}Z_{qs}} \tag{24}$$

and

$$R_p = \sqrt{Z_{po}Z_{ps}} \tag{25}$$

when 3–4 is terminated in R_q for maximum efficiency.

Open- and short-circuit measurements enable us to compute the optimum efficiency from equation 17 only if the transfer admittance K_a is known. If the reciprocal theorem holds, $K_a = K_b$ and K_a can be determined from (23). The optimum efficiency is then

$$\eta_{max} = \frac{1 - \sqrt{\frac{Z_{ps}}{Z_{po}}}}{1 + \sqrt{\frac{Z_{ps}}{Z_{po}}}} \tag{26}$$

Table II. Performance of Double-Balanced Modulator (Ideal Reversing Switch) for Various Input and Output Terminations

Modulator Terminations				Modulator Impedance		Modulator Loss or Efficiency	
Input Circuit		Output Circuit					
Signal	Others	Signal	Others	Input Signal	Output Signal	Voltage Ratio	Decibels
R	R	R	R	R	R	$\frac{2}{\pi}$	3.9
R	any value	R	R	R		$\frac{2}{\pi}$	3.9
R	R	R	0	$\frac{2R}{\pi^2-2}$	R	$\frac{2}{\pi}$	3.9
R	R	R	∞	$\frac{(\pi^2-2)R}{2}$	R	$\frac{2}{\pi}$	3.9
R	$\frac{(\pi^2-2)R}{2}$	$\frac{(\pi^2-2)R}{2}$	0	R	$\frac{\pi^2(\pi^2-2)R}{6\pi^2-16}$	$\frac{\pi}{\sqrt{2(\pi^2-2)}}$	2
R	$\frac{2R}{\pi^2-2}$	$\frac{2R}{\pi^2-2}$	∞	R	$\frac{(6\pi^2-16)R}{\pi^2(\pi^2-2)}$	$\frac{\pi}{\sqrt{2(\pi^2-2)}}$	2
R	0	R	0	0	0		∞
R	∞	R	∞	∞	∞		∞
R	0	R	∞	$\frac{\pi^2R}{4}$	$\frac{4}{\pi^2}R$	$\frac{4\pi}{4+\pi^2}$	0.85
R	∞	R	0	$\frac{4}{\pi^2}R$	$\frac{\pi^2}{4}R$	$\frac{4\pi}{4+\pi^2}$	0.85
R	0	$\frac{4}{\pi^2}R$	∞	R	$\frac{4}{\pi^2}R$	1	0
R	∞	$\frac{\pi^2}{4}R$	0	R	$\frac{\pi^2}{4}R$	1	0
R_s	R_s'	R_r	R_r'	Z_i*	Z_0*	η*	

*$Z_i = \frac{\pi^2R_r'(R_r+R_s')+4(R_r-R_r')R_s'}{\pi^2(R_r+R_s')-4(R_r-R_r')}$ $\quad Z_0 = \frac{\pi^2R_s'(R_s+R_r')+4(R_s-R_s')R_r'}{\pi^2(R_s+R_r')-4(R_s-R_s')}$

$\eta = \frac{4\pi(R_r'+R_s')\sqrt{R_sR_r}}{\pi^2(R_s+R_r')(R_r+R_s')-4(R_r-R_r')(R_s-R_s')}$

If the input signal generator has an internal impedance, most efficient energy delivery to the modulator will, of course, result if this impedance is made equal to R_g.

Equivalent T, π, and bridge networks can obviously be drawn from the open- and short-circuit measurements as in four-terminal linear networks.

It appears that even in a plate- or grid-circuit modulator the formulas of equations 24, 25, and 26 can be applied to the plate or grid circuit, respectively, where the signals are small compared to the carrier, inasmuch as the modulating parts of these circuits are linear and bilateral with no internal energy sources.

Double-Balanced or Reversing-Switch Modulator*

A number of interesting conclusions can be reached about copper-oxide modulators by assuming that the copper oxide acts like a switch having a low resistance value when the positive half-cycle of the carrier voltage is across the disk and a high resistance value during the negative half-cycle. The circuits of figures 2*c*, 2*d*, or 2*e* can then be represented by the equivalent circuit of figure 8.

* Referred to in the German literature as the "ring modulator."

The input signal generator V_0 is applied out of an input circuit impedance Z_a, and the output signal is delivered to the output circuit impedance Z_b. Both Z_a and Z_b in general will be functions of frequency.

If $Z_a = Z_b = R$ at all frequencies it can easily be shown that the circuit will operate most efficiently for

$$R = \sqrt{R_rR_f} \tag{27}$$

The signal input current will then be the only frequency in i_a.

$$i_a = \frac{V_0}{2R} \tag{28}$$

From the properties of lattice networks it follows, that

$$i_b = \frac{V_0}{2R} \cdot \frac{\sqrt{\frac{R_r}{R_f}}-1}{\sqrt{\frac{R_r}{R_f}}+1} \cdot f(t) \tag{29}$$

where

$$f(t) = \begin{cases} +1 \text{ for positive half-cycle of carrier} \\ -1 \text{for negative half-cycle of carrier} \end{cases}$$

Letting

$$f(t) = \frac{4}{\pi}\left(\cos ct - \frac{1}{3}\cos 3\,ct + \frac{1}{5}\cos 5\,ct \ldots\right)$$

and

$$k = \frac{\sqrt{\frac{R_r}{R_f}}-1}{\sqrt{\frac{R_r}{R_f}}+1} \tag{30}$$

$$i_b = \frac{V_0k}{2R} \cdot \frac{4}{\pi}\left[\cos ct - \frac{1}{3}\cos 3ct + \frac{1}{5}\cos 5ct \ldots\right] \tag{31}$$

The magnitude of the single-sideband output current is

$$i_{1+} = i_{1-} = \frac{2k}{\pi} \cdot \frac{V_0}{2R} \tag{32}$$

and the efficiency

$$\eta = \frac{4}{\pi^2}k^2 \tag{33}$$

In addition currents flow in the output circuit at both sidebands of all odd harmonics of the carrier frequency. These can be represented by i_{3+}, i_{3-}, i_{5+}, etc. No currents flow at the sideband frequencies of the even harmonics of the carrier, i_{2+}, i_{2-}, . . .

If V_0 should be replaced by an equal amplitude generator at any of the sideband frequencies, V_{1+}, V_{2-}, etc., then the input current would in any case be

$$i_{1+} = \frac{V_{1+}}{2R}, I_{2-} = \frac{V_{2-}}{2R}, \text{ etc.}$$

The correspondence between the magnitudes of these entering currents and the magnitudes of the output currents at the modulation product frequencies are shown in table I. Reciprocal relations between the driving voltage at one frequency and the output current at another frequency are obvious.

Generalized Reflection Theory

Superposition permits us to apply simultaneously driving forces of the frequencies tabulated above in any relative phases and amplitudes that we care to choose on either side of the modulator. If simultaneously I_0 is applied on one side of the modulator and

$$(I_{1+})\ \frac{2k}{\pi} \cdot \frac{Z_{1+}-R}{Z_{1+}+R}$$

is applied to the other set of modulator terminals, then the total current at the output terminals at the sideband frequency (1+) will be

$$(I_{1+})\frac{2k}{\pi} \cdot \left[1 - \frac{Z_{1+}-R}{Z_{1+}+R}\right] \tag{34}$$

This is equivalent to saying that a resistance R at the sideband frequency (1+)

The Magnesium-Copper Sulphide Rectifier Battery Charger for Railroad Passenger Cars

By C. A. KOTTERMAN
NONMEMBER AIEE

Synopsis: When the railroads began air conditioning their trains, adequate charging of the storage batteries associated with air-conditioning systems became an important factor in the new development. The capacity of the axle driven d-c generator charger was increased; however, supplementary charging was frequently necessary or desirable, particularly when the axle generators were not operating. The railroads met this problem by using portable motor generator sets, wiring their stations and yards with standby service and through the use of small, compact, dry-disk rectifier battery chargers of sufficient current capacities to charge one or two car batteries simultaneously. The first rectifier developed for this service made use of the magnesium-copper sulphide dry-disk type. The mechanism of this rectifier is here briefly discussed, design features enumerated, and the type of rectifier battery chargers developed for railroad use described.

STORAGE BATTERIES were first added to railroad passenger and Pullman coaches about 40 years ago to provide power for electric lights which replaced the gas and oil lamps. These batteries were charged by means of axle-driven d-c generators. Electric ventilating fans were added later but under normal operating conditions the generators adequately charged the batteries. With the advent, however, of electro-mechanical air-conditioning equipment on railroad cars demanding d-c currents varying from 150 to nearly 300 amperes, an entirely new concept of storage-battery equipment and charging had to be worked out. In a few short years the battery load has increased from 25 to 50 amperes to nearly 300 amperes per car on some of the present-day streamlined completely air-conditioned trains. The combined efforts of storage-battery, air-conditioning, and rolling-stock engineers have accomplished a truly remarkable result in providing high-intensity indirect illumination together with air conditioning on modern trains.

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This improvement in the traveling public's comfort and convenience has created many difficult problems which had to be solved. Among them may be mentioned the development of a 1,000-ampere-hour-capacity storage battery small enough in size and weight to be mounted on a coach. Adequate charging facilities had to be developed to meet the increased loads on batteries. All of this has become a reality without increasing the size of the trucks or other parts of the cars. Under normal train operating conditions, the axle-driven generator operates enough of the time to charge the batteries adequately. During the summer months, however, when the air-conditioning equipment is used to the limit to meet hot-weather conditions, supplementary or so-called "yard" charging often becomes necessary. Also, in bad winter weather when snow and ice affect the axle drive and the battery ampere-hour capacity is lowered, supplementary charging is also required.

The railroads have handled this situation in several ways. Some coach yards and stations have been equipped with d-c charging lines supplied by one or more motor generator sets. This is a costly system to install, requiring quite an investment in copper feeder cables to handle the large charging currents necessary without introducing too much IR drop in the charging lines.

Portable or mobile motor generator sets usually of sufficient capacity to charge the batteries on two cars simultaneously are also used. They meet the need for supplementary charging equipment but their weight and lack of easy maneuverability often restrict their use in badly congested coach yards, particularly in the winter with snow and ice hampering their movement.

Some railroads have installed 220-volt 60-cycle three-phase systems for standby service in their yards and stations. Many of the air-conditioning systems on trains include a 10–20-horsepower three-phase motor for driving the compressor associated with the air-conditioning equipment on a standing car. This is extra weight that has to be carried with the car for the sole purpose of providing standby service. The 220-volt a-c supply is, however, readily available for battery charging purposes and at a reasonable cost.

About two years ago, when the charging problem was fully realized, the P. R.

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has been connected to the output terminals of the modulator and in this resistance is an internal zero-impedance generator of voltage

$$2R(I_{1+})\ \frac{2k}{\pi}\cdot\frac{Z_{1+}-R}{Z_{1+}+R} \qquad (35)$$

This resistance R at sideband frequency $(1+)$ must be infinite at all other frequencies, if in parallel we assume another resistance of R at all frequencies except $(1+)$ at which it is infinite.

The equivalent impedance at frequency $(1+)$ at the modulator terminals connected to the $(1+)$ resistance with its internal generator, is the ratio of $(1+)$ voltage to $(1+)$ current.

$$Z=\frac{\frac{2k}{\pi}I_{1+}\cdot 2R-\frac{2k}{\pi}\cdot I_{1+}\cdot\left[1-\frac{Z_{1+}-R}{Z_{1+}+R}\right]R}{\frac{2k}{\pi}I_{1+}\cdot\left[1-\frac{Z_{1+}-R}{Z_{1+}+R}\right]} \qquad (36)$$

which reduces to

$$Z=Z_{1+} \qquad (37)$$

Z_{1+} may be real or complex as it involves only the amplitude and phase of the superimposed voltage of upper-sideband frequency. It can readily be seen then that the solution for current flow at this frequency of equation 34 is identical with the case of linear networks in which the current is expressed as that flowing in a matched circuit modified by a reflection factor. Reflection from any modulation-product frequency can be similarly treated.

A number of cases have been worked out of efficiencies and impedances in such modulators for transmission between an input signal and a single-sideband output signal. The modulating element has been assumed perfect ($k = 1$) and the terminations pure resistances. The results are shown in table II.

Figure 1. Mobile charger with louvred weatherproof cover removed

Mallory and Company, Inc., working in close co-operation with engineers of several railroads, evolved a heavy-duty dry-disk type of rectifier for converting three-phase 60-cycle current to direct current of sufficient current output to handle the air-conditioning load on a standing car or to charge one or two car batteries simultaneously. The current capacity of this rectifying unit together with the small physical size and weight of the charger made possible a practical battery charger easy to wheel around with operation fully automatic and reasonably foolproof. Weighing but 600 pounds with a width of 20 inches, capable of delivering 200 amperes into a 16-cell battery or 100 amperes into a 32-cell battery, this charger can be manipulated in the narrow space between cars in coach yards.

The rectifying element used in these battery chargers is of the contact type employing a magnesium-copper sulphide junction, the invention of Samuel Ruben. Such a rectifier consists essentially of a conductor and semiconductor in more intimate contact than physical juxtaposition and pressure can give.

There are three widely known types of contact rectifiers, namely, the copper-copper oxide, the iron-selenium, and the magnesium-copper sulphide rectifiers. During recent years both the copper-copper oxide and the magnesium-copper sulphide types have been developed to the point where they are capable of handling large currents per unit area. The iron-selenium rectifier has never been considered seriously as a heavy-duty type.

The copper-copper oxide rectifier of the sprayed-plate type has a current capacity of approximately 1.2 amperes per square inch of rectifying area when properly ventilated, the plate junction serving also as its own radiator to provide sufficient cooling area to dissipate heat generated during operation.

The magnesium-copper sulphide rectifying junction has a current capacity of approximately 60 amperes per square inch when properly ventilated. Due to the high current density at which the magnesium-copper sulphide rectifier can be worked, it is possible to build such a rectifier for large d-c outputs in a very small physical size. As a matter of fact, the type illustrated in figure 1 is but 18 inches in diameter by 12 inches high, weighs 100 pounds including ventilating system, and delivers 10 kw. These figures, of course, do not include the three-phase transformer.

Before describing the various types of rectifier battery chargers which have been developed for the railroad application, it is desirable to consider a-c circuit systems in connection with rectifiers for battery charging. Rectified voltages are frequently less than the a-c line voltages, therefore it is necessary to use some form of step-down transformer to reduce the line voltage to a suitable input value to the rectifier. The use of a transformer introduces transformer design and suitable transformer-rectifier circuits into the rectifier picture. The very simplest trans-

Figure 2. Transformer-rectifier circuits

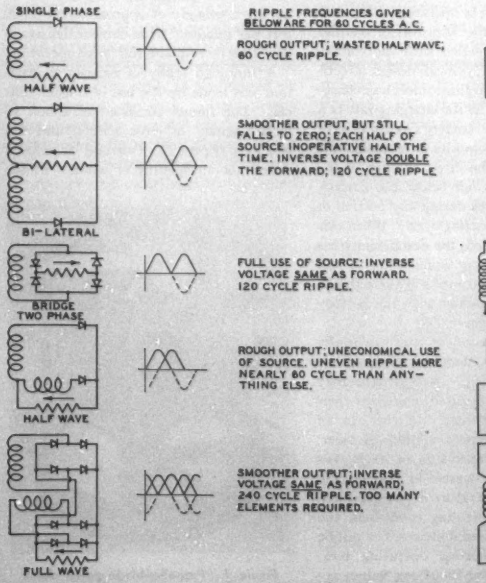
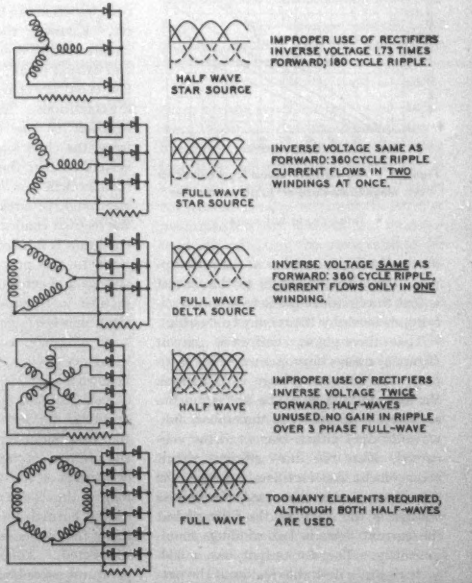

SINGLE PHASE
HALF WAVE
RIPPLE FREQUENCIES GIVEN BELOW ARE FOR 60 CYCLES A.C.
ROUGH OUTPUT; WASTED HALFWAVE; 60 CYCLE RIPPLE.
BI-LATERAL
SMOOTHER OUTPUT, BUT STILL FALLS TO ZERO; EACH HALF OF SOURCE INOPERATIVE HALF THE TIME. INVERSE VOLTAGE DOUBLE THE FORWARD; 120 CYCLE RIPPLE.
BRIDGE TWO PHASE
FULL USE OF SOURCE: INVERSE VOLTAGE SAME AS FORWARD. 120 CYCLE RIPPLE.
HALF WAVE
ROUGH OUTPUT; UNECONOMICAL USE OF SOURCE. UNEVEN RIPPLE MORE NEARLY 60 CYCLE THAN ANY-THING ELSE.
FULL WAVE
SMOOTHER OUTPUT; INVERSE VOLTAGE SAME AS FORWARD; 240 CYCLE RIPPLE. TOO MANY ELEMENTS REQUIRED.

Figure 3. Transformer-rectifier circuits


HALF WAVE STAR SOURCE
IMPROPER USE OF RECTIFIERS INVERSE VOLTAGE 1.73 TIMES FORWARD; 180 CYCLE RIPPLE.
FULL WAVE STAR SOURCE
INVERSE VOLTAGE SAME AS FORWARD: 360 CYCLE RIPPLE CURRENT FLOWS IN TWO WINDINGS AT ONCE.
FULL WAVE DELTA SOURCE
INVERSE VOLTAGE SAME AS FORWARD: 360 CYCLE RIPPLE, CURRENT FLOWS ONLY IN ONE WINDING.
HALF WAVE
IMPROPER USE OF RECTIFIERS INVERSE VOLTAGE TWICE FORWARD. HALF-WAVES UNUSED. NO GAIN IN RIPPLE OVER 3 PHASE FULL-WAVE
FULL WAVE
TOO MANY ELEMENTS REQUIRED, ALTHOUGH BOTH HALF-WAVES ARE USED.

former-rectifier circuit known is illustrated in figure 2. This is a half-wave single-phase circuit producing a very rough d-c output with an inoperative half-wave resulting in a 60-cycle ripple. A somewhat better circuit is the bilateral where the d-c output is smoother but the direct current falls to zero. Each half of the a-c source is inoperative half the time. The inverse voltage per individual rectifier junction is double the forward voltage; however, this circuit has the advantage of a 120-cycle ripple. Probably the most efficient and satisfactory circuit for single-phase operation of rectifiers is the full-wave bridge. This circuit makes full use of the a-c source; the inverse voltage is the same as the forward voltage and the ripple is 120 cycles.

The simplest polyphase circuit is the two-phase half-wave resulting in rough d-c output, uneconomical use of the a-c source, inverse voltage the same as the forward voltage, and has a 240-cycle ripple. The chief objection to this circuit is that the circuit requires too many rectifying elements for the required d-c output.

The three-phase half-wave circuit (figure 3) makes improper use of the rectifier. The inverse voltage is 1.73 times the forward voltage. The d-c output has a 180-cycle ripple. The three-phase full-wave bridge, either star or delta connected, offers the most efficient circuit arrangement for rectifiers. Where the a-c source is star connected, the inverse voltage is the same as the forward but the current flows in two windings simultaneously. The d-c output has a 360-cycle ripple, a desirable feature if the output has to be filtered. The delta connection of the a-c source has the advantage that current flows only in one winding during a rectifying cycle. The inverse voltage is the same as the forward and the d-c output carries a 360-cycle ripple. The last-mentioned circuit arrangement has been adopted on all our heavy-duty rectifiers operating from three-phase sources.

In designing a rectifier for heavy-current battery charging two essential rectifier fundamentals are of considerable importance. One is voltage ratio, defined as the ratio of direct voltage output to alternating voltage input. Maximum voltage ratio is a function of how much alternating voltage one rectifying junction can have impressed across the junction without breaking down the insulating film between the elements of the junction. The other is the current ratio, defined as the d-c output to a-c input. Maximum current ratio is a function of the maximum safe current density at which the rectifying junction can be operated with stability. Knowing the transformer-rectifier circuit system together with the voltage and current ratios, one can design a rectifier for battery charging to meet any charging conditions. As the charging rate is a function of the battery electromotive force, the chief requisite is to design the system so that the direct voltage of the rectifier will not fall below the battery electromotive force during any portion of the rectifier conducting cycle. When this condition is fulfilled, the design simplifies itself to the proper application of the voltage and current ratios of the sulphide rectifier in conjunction with the battery electromotive force.

All contact rectifiers are essentially resistance devices, therefore they generate heat when rectifying. The life expectancy of such rectifiers is based mainly on their operating temperature. In the case of the magnesium-copper sulphide rectifier, the optimum temperature is 90 degrees centigrade or 190 degrees Fahrenheit. So long as this temperature is not exceeded, during normal operating conditions, the life of the copper sulphide rectifier will be unaffected. Abnormal operating temperatures exceeding the above values appreciably will have some affect on life. As a matter of interest, we have conducted a life test, in excess of 5,000 hours, on a magnesium-copper sulphide rectifier of the type used in our railroad battery chargers, at operating temperatures averaging 130 degrees centigrade or 266 degrees Fahrenheit with little effect on the life of the rectifier. The lower the operating temperature, the longer the life when other operating conditions are normal. Heat generated at the rectifying junction must therefore be removed faster than by simple convection cooling if the rectifier is to deliver large direct currents. The magnesium-copper sulphide rectifier of 1.7 square inches of rectifying area with 3.5 inches square radiator plates or cooling fins will handle 100 amperes direct current safely when placed in a stream of air having a velocity of approximately 2,000 feet per minute. This current density is based on three-phase full-wave operation.

A thorough study of rectifier ventilation was made by the use of a wind tunnel. The tunnel consisted of a box 18 inches square in cross section and ten feet long (figure 4). One end was closed except for an opening or window in the

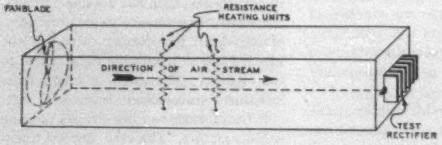


Figure 4. Wind tunnel

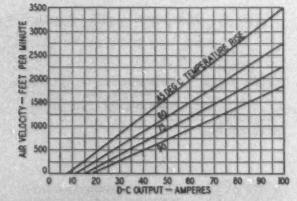


Figure 5. Air velocity versus load curves for the magnesium-copper sulphide rectifier

Three-phase full-wave

Figure 6. Drum housing with centrifugal-blower wheel

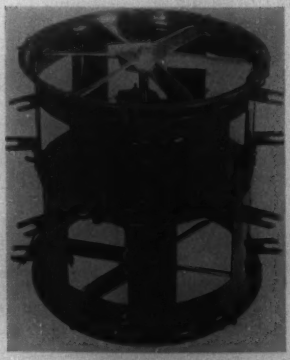


Figure 7. Propeller-blade power dome

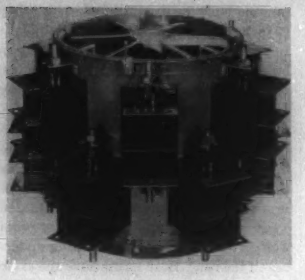


Figure 8. Propeller-blade power dome with rectifiers

center into which the test rectifier was set. The other end of the box was attached to a blower system capable of providing air velocities as high as 5,000 feet per minute. Electric heating elements were placed midway between the ends inside the box to raise the temperature of the air stream for the purpose of studying the behavior of the test rectifiers at elevated temperatures. The compiled data from the wind-tunnel tests enables us to design a ventilating system for any rectifier-transformer combination and to predict within engineering limitations the operating temperature of a power rectifier for any given ambient temperature. Figure 5 is a family of curves, air-velocity versus load as obtained by the wind-tunnel tests.

To increase the current-handling capacity of the magnesium-copper sulphide rectifier forced cooling has been developed which led to the study of accelerated air flow through rectifiers. After trying various methods, one was finally evolved of supporting the rectifier elements in the wall of a hollow drum structure, mounting a pressure-type centrifugal blower wheel inside the drum. Figure 6 shows one of the earlier models employing this construction. Air is drawn in through the opening in the center of the fan rotor, then discharged tangentially from the blades through the rectifiers. This permits a very compact construction together with efficient cooling.

The rectifiers are placed symmetrically around the fan-wheel housing. This construction lends itself to very simplified wiring of the rectifiers. The whole structure is known as the "d-c power dome." It is usually supported on top of another housing in which the power transformer is placed. The air discharged through the ventilating fins of the rectifier is first drawn through and around the coils of the transformer, therefore giving the transformer forced cooling. In this way smaller and lighter-weight transformers may be employed.

The centrifugal-type fan wheel is essentially a pressure blower. It delivers large volumes of air with comparatively low velocities. Where the rectifier cooling fins are close together in order to make as compact assembly as possible, high velocity through the fins is desirable. A fan which would deliver high air velocity rather than great volumes of air was desired and this was developed in conjunction with manufacturers of propeller-type fan blades. The method of employing this type fan is shown in figure 7.

A one-third-horsepower motor is supported inside the drum cage. The motor shaft has a double extension so that two fans, one right hand and one left hand, may be rotated simultaneously. Air is drawn in by both propellers building up a pressure inside the drum which is discharged out through the rectifiers mounted in openings in the drum (figure 8).

In the two cooling methods just described, the rectifiers are mounted around a drum or cage. A modification of this principle is employed in a very recent development of forced-cooled rectifiers for large power outputs. In this design the rectifiers are mounted radially in a plane around the motor which drives a single fan. It develops an air pressure inside the housing, forcing the air out through the rectifiers (figure 9).

The railroad battery chargers have been developed in two forms—the "mobile" charger for platform or yard charging and the "on-a-car" type for mounting on and traveling with a car. Both types consist essentially of a three-phase power transformer, three-phase full-wave bridge rectifiers with ventilating system, a chassis or mounting device and housing together with provision for altering the charging rate and compensating for line-voltage variations. Protective circuits are also incorporated.

The mobile charger with principal dimensions shown in figure 10 is manufactured in two types. In one form the

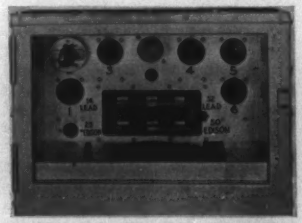


Figure 11. Mobile-charger control panel showing "wander" plug and tap-changing receptacles

charging rate is varied by means of primary taps on the three-phase power transformer (see figure 11). In other models a self-regulating transformer is employed. In this type a sensitive voltage relay across the d-c output of the rectifier maintains a constant d-c output by automatically adjusting the turns ratio of the transformer to compensate for line-voltage variations (figure 14). Figure 12 is a typical charging curve obtained with a charger equipped with a manual control. Figure 13 is a charging curve using the type having the self-regulating transformer.

As the life of the rectifying units depends considerably on proper and continuous ventilation, it is essential that the motor associated with the ventilating system be interlocked with the hold-in coil of the main magnetic contactor or be provided with an individual contactor with overload protection interlocked with the main contactor. A single-phase 220-volt motor is employed so that phase reversal

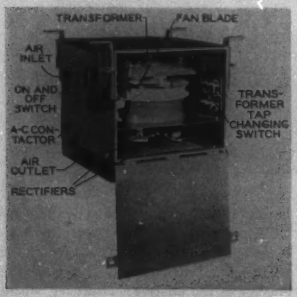


Figure 9. Undercar charger

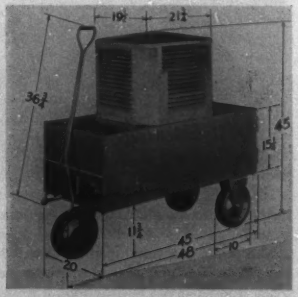


Figure 10. Mobile charger

will not affect the direction of rotation as the fans must rotate in one direction only. The "on and off" switch which starts and stops a charge is also in the fan circuit. It is provided with a thermal

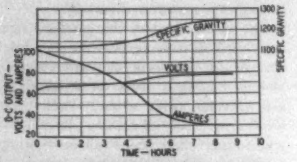


Figure 12. Typical charging curve from manually operated mobile charger

For 600-ampere-hour lead battery

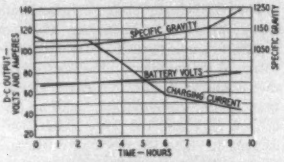


Figure 13. Typical charging curve from self-regulating mobile charger

For 600-ampere-hour lead battery

overload so in case of fan motor failure, the a-c power to the transformer will be disconnected.

The charging rate on the manually controlled model is varied by means of a "wander" plug and six primary tap receptacles as shown in figure 11. It, however, does not compensate automatically for line-voltage variations. This simple method provides a wide range of charging rates from a few amperes to the full output of the machine and has proved quite adequate for battery charging. Field experience has shown that about 90 per cent of the use of these chargers is to pump as many ampere-hours into a battery as possible in a short time, or to carry the air compressor load of a standing car with the battery floating across the rectifier. Rarely have these periods exceeded three hours.

The charging rate on the automatic regulating type is set by turning a control knob located on the control panel. The charging rate will remain constant until the electromotive force of the battery has risen to a value which can no longer be compensated for by the self-regulating feature at which time the charge will start tapering abruptly, a highly desirable feature in storage-battery charging. The self-regulating feature also maintains a constant charge during line-voltage variation of plus or minus $7\frac{1}{2}$ per cent for any rough setting of the three primary line-voltage taps. These rough settings together with the plus or minus $7\frac{1}{2}$ per cent regulation provide constant output from 193-volt lines to 253-volt lines.

The fully automatic type also incorporates a current-limiting control which changes the turns ratio of the transformer should the charging rate inadvertently be increased beyond the setting for maximum safe continuous operation.

The rectifiers are wired up in two banks (figure 15), each consisting of two full-wave three-phase bridges in series, providing approximately 37–49 volts d-c output each. A double-pole double-throw switch conveniently mounted enables the two banks to be connected in parallel to provide 37–49 volts at 200 amperes to charge one or more 16-cell lead batteries or 25 cells of Edison batteries, or they may be connected in series to charge a 32-cell lead or 50-cell Edison battery at 100 amperes. Two standard d-c charging receptacles mounted at one end of the charger are connected in parallel so that two batteries may be charged simultaneously. An ammeter shunt is connected into the circuit of each charging receptacle. An ammeter, common to both circuits, indicates the charging current in either charging line. It is practical to charge a 16-cell lead and a 25-cell Edison battery simultaneously if a small series resistor is added to the lead battery charging line.

Both types are equipped with standard railroad three-phase four-wire a-c receptacles, the fourth conductor serving as a ground.

The machines are readily wheeled around on ten-inch diameter, two-inch tread rubber-tired antifriction wheels. As already stated, weighing but 600 pounds and but 20 inches wide, they possess a maximum of maneuverability.

The equipment is fully protected in louvered steel housings and may be operated safely and satisfactorily in any kind of weather.

The "on-a-car" type has been developed in two forms. One shown in figure 16 is intended to be mounted in the clerestory. The other illustrated in figure 9 is enclosed in a ventilated weather-, ballast-, and cinder-proof welded steel housing for mounting underneath the car. Both forms have the same type transformers and rectifiers together with the control and protective features of the mobile types, but because they are designed to charge a particular battery, they do not need to have the flexibility of charging rate of the mobile type. The clerestory form, in operation on several railroads, supplies 100 amperes into a 16-cell lead or 25-cell Edison battery and 80 amperes into a 32-cell lead or 50-cell Edison battery and weighs approximately 290 pounds. Larger-capacity chargers up to 200 amperes into 16-cell lead or 25-cell Edison or 100 amperes into 32-cell lead or 50-cell Edison can be built of small enough size and weight to be mounted in the clerestory if desired.

The undercar type, due to its weatherproof housing, weighs more than the clerestory model but the over-all dimensions are practically the same.

Manual control of the "on-a-car" type battery charger is not needed as the regulation of the transformer-rectifier combination automatically takes care of the charging rate depending upon the specific gravity of the battery. However, where it is necessary or desirable automatically

Figure 14. Self-regulating three-phase power transformer

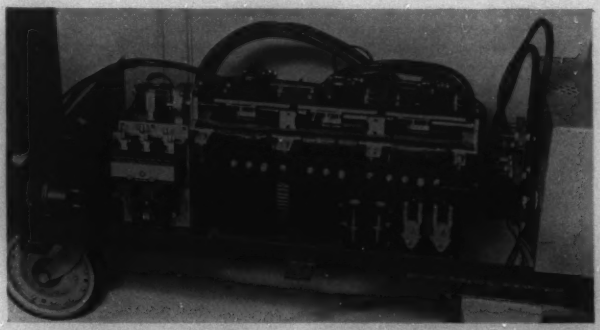
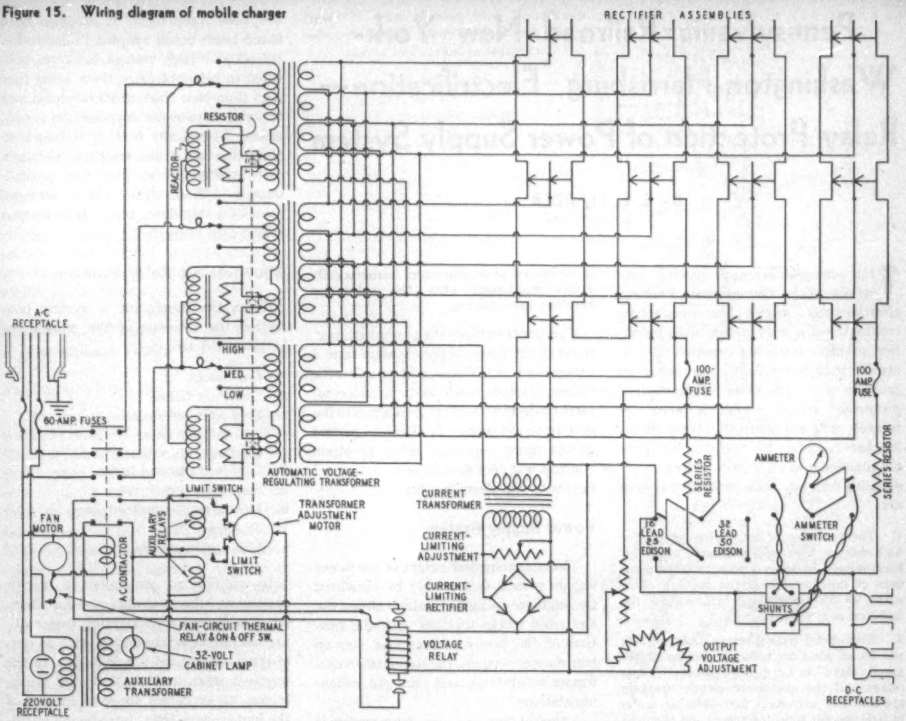


Figure 15. Wiring diagram of mobile charger



to adjust for line-voltage variation, a self-regulating transformer can be included in the equipment.

Both types operate directly from the 220-volt three-phase standby supply. They require no attention other than connecting or disconnecting this supply. One model is provided with an automatic tapering feature which reduces the charging rate to a mere trickle charge when the voltage of the battery has reached a predetermined value. Should this charger be left on inadvertently for a longer period of time than necessary to complete a normal charging cycle, the trickle rate will automatically come into operation thus preventing undue gassing of the battery.

Figure 16. "On-a-car" charger

Although none has been built as yet for this service, designs are ready for an undercar type that will carry the compressor load of a stationary car. This model would eliminate the a-c standby motor and would provide auxiliary charging whenever required.

Rectifier battery chargers possess certain operating features not found in other types. They are light in weight, handle easily, and are compact enough to be used in crowded coach yards. As no heavy rotating parts are employed, they are exceedingly quiet in operation. Maintenance is reduced to a minimum as there are no commutating devices or brush wear. A very desirable feature is that the rectifier battery chargers start on load with a starting current approximately the same as the running current. This enables them to be operated directly off the 220-volt three-phase standby service.

The possibility of polarity reversal is eliminated. This feature together with the fact that the reverse current from the battery through the rectifier is of the order of an ampere, eliminates the need of reverse-current relays.

The magnesium-copper sulphide rectifier battery charger has an over-all efficiency of approximately 50 per cent. The efficiency curve is practically flat from 25 per cent full load to 125 per cent full load. The efficiency of the rectifier itself is about 55 per cent and remains at this value throughout the life of the rectifier. Very recent developments indicate that a higher efficiency may be expected of the copper-sulphide rectifier in the near future, together with greater stability of operation and even longer life than the present type.

Pennsylvania Railroad New York-Washington-Harrisburg Electrification—Relay Protection of Power Supply System

By E. L. HARDER
ASSOCIATE AIEE

THE completion and placing into service of the Pennsylvania Railroad electrification marks the satisfactory conclusion of a relay design and application problem involving considerable pioneering work in this field. The protection problem is the provision of a system of protective relays, which in event of trouble, will automatically open circuit breakers to isolate the faulty section from the remainder of the power system. Outstanding features of the protective system are:

1. The provision of a relaying system for high-voltage lines operated with very few high-voltage breakers and with large numbers of taps, involving the opening of as many as 30 low-voltage breakers for the isolation of a single fault.

2. High-speed trolley relays, inaugurating the use of what are today known as "high-speed relays" in a-c power systems. These relays and the associated circuit breakers are not only extremely fast, clearing faults in 0.04 second total for relays and breaker, but the relays are also very selective, clearing fault currents less than maximum loads and effecting simultaneous operation over 90 per cent of the section length. High-speed a-c circuit breakers, high-speed "distance measuring" relays, transient shunts, and the load presetter, are all new developments associated with this electrification.

3. Use of locomotives and multiple-unit cars not having any main circuit breaker. Trolley circuit breakers at substations open for major faults on the moving equipment. Locomotive and substation relays are so co-ordinated as to disconnect automatically faulty equipment after the substation breakers have opened.

This paper outlines the general arrangement of the power supply system from a protective point of view, and describes the system of relays developed to provide complete protection from the generators to the motive power units. It discusses several of the more important relay problems which it was necessary to solve in connection with the electrification.

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The suggestions and recommendations of Mr. Griffith, electrical engineer of the Pennsylvania Railroad, and his associates, in the development of this over-all protective system are gratefully acknowledged. Also his helpful assistance in the preparation of this paper. The co-operation of Mr. Watkins and his associates in the consulting firm of Gibbs and Hill are likewise gratefully acknowledged. As stated in the text, the relaying of this system was largely a joint effort of the Pennsylvania Railroad, General Electric Company, and Westinghouse. Only that portion for which the Westinghouse company supplied all or part of the equipment is described.

Power Supply System

The comprehensive extent of the power supply system may readily be visualized by reference to figure 1 which shows the electrified tracks together with the location of the power sources and step-up transformer stations, the step-down transformer substations, and principal switching stations.

A typical portion of the power system is shown in figure 2. Altogether 25-cycle power is available at seven locations, either by steam or hydro generation, or in most cases by frequency conversion from 60-cycle power systems in the area served. This 25-cycle power is transmitted over nearly 1,100 miles of 132-kv single-phase lines throughout the 674 route miles of electrified territory. It is distributed at 11 kv over 2,189 miles of trolley from 61 transformer substations, the majority of which are located 6 to 12 miles apart.

The absence of 132-kv breakers at step-up and step-down transformer stations is a notable feature. Each transmission-line section with its connected step-up and step-down transformers is cleared as a unit by the low-voltage breakers in event of fault.

The transmission lines are "looped in" to the 25-cycle generating busses through the step-up transformers. This gives rise to the designation "looped-in" system in distinction to a system in which high-voltage lines are continuous past generating stations. While the "looped-in" system was adopted primarily on account of circuit breaker capacity and to limit telephone interference, it has also been found much better adapted to protection by relays. High-voltage lines are provided in balanced pairs, there being four lines from New York to Philadelphia and two elsewhere as far as protection is concerned. Physically both of the lines do not follow all of the trackage, although each station has at least two possible sources of feed. The general arrangement of a step-down transformer station is indicated in figure 3.

The Over-All Relay Problem

From the standpoint of system protection the elements of the system to be protected are:

1. Generators.
2. Generator busses.
3. Step-up transformers.
4. Transmission lines.
   (*a*) Line-to-line faults.
   (*b*) Line-to-ground faults.
5. Step-down transformers.
6. Low-voltage or trolley busses.
7. Trolleys.
8. Motive power units.

In addition to protection of specific apparatus, relays are also used for effecting the desired sectionalizing under abnormal operating conditions such as out-of-synchronism and low voltage. In the terminal areas, at New York and Washington, 12-kv cables are used instead of the high-voltage lines, introducing an additional element to be protected. Special protection is also used on the 132-kv cables through Baltimore.

It is evident that the protection of the various elements enumerated must be accomplished with careful consideration of the co-ordination with the protection of other elements so that only the faulty section will be disconnected. The more important of these co-ordination problems will be discussed in the subsequent paragraphs.

A-C Network Calculator

System voltages and currents under fault and load conditions form the fundamental basis for the relay application and the determination of these necessary data is a major problem. For the earlier stages of the electrification many of these data were obtained analytically. However, for the relaying of the complicated system involved in the through electrification, these data were obtained on the a-c network calculator developed by the Westinghouse company and owned and operated by the railroad (figure 4).

Generators

In addition to the conventional differential protection, generators are equipped in most cases with induction-type overcurrent relays having time and current selectivity with overcurrent relays used on the transmission lines. An additional machine protective feature is used on some of the frequency changers to prevent building up resonant torsional stresses when slipping poles. This device counts power reversals at high current, and trips for a fixed number occurring within a definite time.[1]

High-Voltage Lines; Line-to-Line Faults

Application Factors

The transmission lines are operated normally balanced and protected by differential current relays at the step-up transformer stations and by sensitive reverse-power relays at step-down stations, as shown in figure 2. The application differs from the normal application of balanced line relays in the following respects. First, the lines are tapped at numerous points between the two ends, where the balance protection is applied and while the unbalanced loading is minimized by operating regulations, provision must be made for normal amounts of unbalance occurring in operation and maintenance. The sectionalizing breakers intervening between generating stations are arranged for simultaneous operation, except for ground faults, to prevent unbalances from this source. Unbalances are created under load conditions by removal of sections of transmission lines between generating stations for servicing and by the removal of step-up and step-down transformers. Thus, the differential current relays are necessarily of a calibrated type which can be set intermediate between unbalance occurring under load conditions and those which will occur under fault conditions.

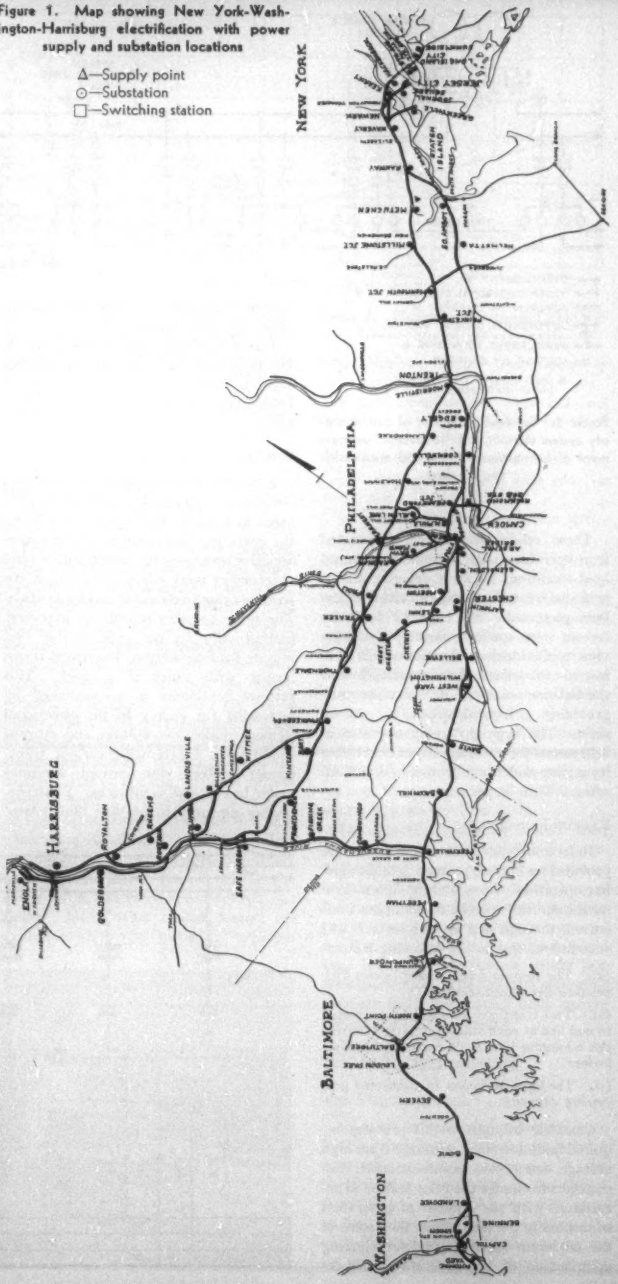
Balance Line Relays

Figure 5 indicates graphically the required "trip" and "not trip" values for the balance line relays at one location and shows the superiority of the *CD* relay characteristic adopted for this application over percentage differential or straight magnitude differential relays which were also considered. Arrows indicate the progression of relaying quantities at the step-up transformer station as other breakers clear from the faulty line.

1. For numbered reference, see end of paper.

Figure 1. Map showing New York-Washington-Harrisburg electrification with power supply and substation locations

Δ—Supply point
⊙—Substation
□—Switching station



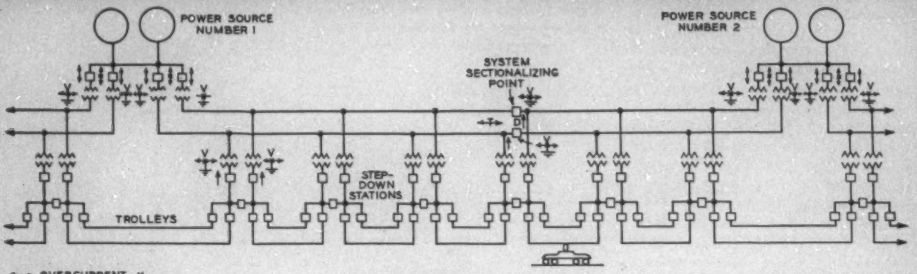


Figure 2. Schematic diagram of power supply system showing the "looped-in" arrangement of transmission circuits and sectionalizing breakers

These relays are further prevented from operating under extreme unbalanced load conditions by fault detector relays, actuated by undervoltage on either of the lines protected. The type *AV* fault detectors were specially developed with a view to minimizing vibration inherent in fast 25-cycle relays when operated close to the balance point and at the same time providing a high drop-out to pick-up ratio. The type *AV* relay operates in 0.10 second for a voltage 10 per cent below its setting and has a drop-out to pick-up ratio of 95 to 98 per cent.

Backup Protection

Induction-type overcurrent relays are provided for backup protection and single-line operation. An extremely high ratio of maximum load current to minimum fault current through step-up transformers was encountered due to the following factors:

(*a*). The step-up transformers have a 250-per-cent-five-minute rating.

(*b*). Two transformers could be connected to one line at each station, greatly lowering the minimum line fault current per transformer.

(*c*). The large variation in connected generating capacity.

Complete solution of this problem required fault detectors, actuated from high voltage, and at some points automatic tap changers to change the relay setting in accordance with the number of generators connected to the bus. Even then some of the minimum faults depend for clearing upon action of the generator quick-response regulators to raise the current above the relay setting.

Figure 6 indicates schematically the relay protection at a step-up transformer station. These relays operate to trip the low-voltage breakers as indicated in figure 2.

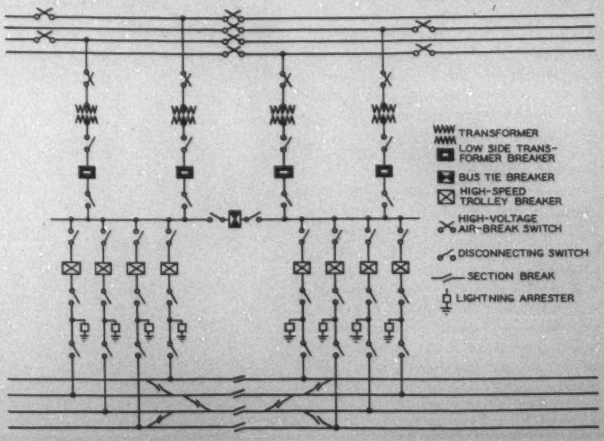
Step-Down Stations

A typical distribution of the fault currents under minimum conditions is indicated in figure 7, and in figure 8 is given the operating characteristic of the supersensitive reverse-power directional-control overcurrent relay developed to meet the stringent requirements of this application. The relay operates rapidly on a reverse current only six per cent of the five-minute load capacity of the power transformer with which it is used. This extreme sensitivity is accomplished by increasing the energy in the directional element under low voltage and current conditions. A saturating current transformer protects the current windings under heavy load conditions. Fault detectors are used to prevent faulty tripping due to feed back to a good line and to assist in energizing a line from the low-voltage side. Figure 9 indicates the reverse-power relay connections for a step-down transformer.

High-Voltage Sectionalizing Points

At Zoo, Perryville, and Thorndale high-voltage breakers are provided for sectionalizing the system. Thorndale and Perryville breakers are operated by the step-down-transformer reverse-power relays at those locations. This arrangement facilitates obtaining selectivity on a time basis with the step-down-transformer relays since both are of the same type. The sensitivity of this arrangement in detecting a fault is indicated by the per cent voltage difference between lines necessary to cause operation. Step-down transformers are four per cent reactance, so that eight per cent voltage difference between lines circulates full load current.

Figure 3. Single-line diagram of power circuits for one of the step-down substations



The relay is responsive to six per cent of full load current and hence to approximately 0.5 per cent voltage difference between high-voltage lines. This is obviously much closer than a differential voltage relay could be set, working directly from the voltages of the two lines. The Zoo breakers are not operated for line-to-line faults unless backup protection is involved.

Sectionalizing breakers of the two parallel lines are arranged to be tripped simultaneously for line-to-line faults to prevent serious unbalance on the good sections.

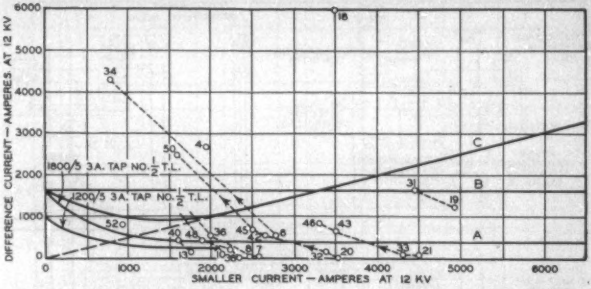


Figure 5. Operating requirement chart for balance line relays at Lamokin

Note: Numbers indicate case numbers of G. and H. data

X = Load condition *A*. Two S.U. out same line at S.H. 100,000-kva load Philadelphia-Washington

A — Type *CD* relay characteristic used

B — Current differential of same one line trip value

C — Fifty-per-cent-slope percentage differential relay

Analysis of Operation

During the first stage of operation after the occurrence of a fault as in figure 7 the step-up transformer breaker nearest the fault and a number of the adjacent step-down-transformer breakers open. This produces a redistribution of fault current causing more reversal through the step-down transformers at other stations and results in their opening in the second or third stage. The majority of faults are cleared in a maximum of two stages, the complete clearing occurring in one second made up of components as follows:

Fault detector relay time —0.08 second.
Relay operating times from 0.1 to 0.5 second.
Breaker operating time from 0.16 to 0.20 second.

With certain emergency setups over-all operating times of 1½ or 2 seconds are required for the complete clearing of a fault. This may include the opening of 30 circuit breakers.

For faults in the Philadelphia-Perryville-Harrisburg area, a high-voltage sectionalizing operation occurs as the first stage followed by the operations indicated above. While the step-up and step-down station relays are delayed by one breaker time to select with the sectionalizing point relays, the over-all clearing time is reduced due to fewer stages of step-down transformer breaker trippings. Important operating advantages result from the limitations of the extent of system affected by a fault.

Figure 4. A-c calculating board installed in Pennsylvania Station, New York City

High-Voltage Lines; Line-to-Ground Faults

The step-up transformers are grounded at the midpoint of the high-voltage windings through comparatively high resistances with the result that when a line is grounded at any one point, that wire is lowered to substantially ground potential throughout its length, the other wire going to twice normal voltage above ground. This makes possible the use of differential voltage relays connected phase to ground at each step-up and step-down transformer station, resulting in prompt sectionalizing of the line, with the system setup in figure 2. It should be noted that had the transmission lines been tied past generating stations, a transmission line throughout the entire length of railroad system would have been affected in the event of a line-to-ground fault at one point. Many other similar factors occurred in which the "looped-in" arrangement of lines at generating stations had great advantages over other proposed operating arrangements.

In the area in which high-voltage sectionalizing breakers are used, two stages of ground relaying are used, sectionalizing of the faulted line occurring as a first stage followed by tripping of transformer breakers on the faulty portion only. Balanced voltage relays of induction type are used throughout, selectivity being obtained on a definite time basis.

The grounding resistor values were chosen of sufficiently low value to prevent arcing ground phenomena (the losses quickly damp out oscillations) but of sufficiently high value that with not over two or three grounding resistors connected per line, the ground fault current would keep inductive interference within permissible bounds. The 330-ohm grounding resistors limit the ground fault current per resistor to 200 amperes.

Trolley Relay Protection

The Requirements

In order to minimize inductive interference, burning of trolleys, and interference with adjacent equipment, it was decided at an early stage in the electrification to use extremely high-speed trolley protection, and accordingly one cycle (0.04 second) total clearing time was set as a requirement. A number of pos-

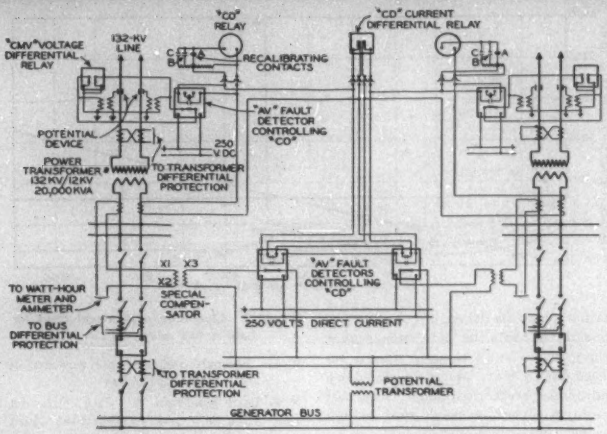


Figure 6. Typical relay connections at a step-up transformer station

Note: Recalibrating contact *A* closed with one generator on line; *B* closed with two generators on line; and *C* closed with three generators on line

sible systems of relaying were investigated, including a 500-cycle superimposed frequency scheme, pilot-wire schemes, and the fundamental-frequency schemes finally adopted.

Two types of relay arrangement were brought out by two different manufacturers. These may be roughly differentiated as a relay type supplied by the Westinghouse Electric and Manufacturing Company and an impulse trip more or less built into the breaker operating mechanism and supplied by the General Electric Company. Both of these arrangements result in one-cycle operating time for relay plus breaker and constitute the first application of what are today known as "high-speed relays" in a-c power systems.

Each trolley section is normally fed from two ends, but with one end open, it must be capable, as far as any relaying limitations are concerned, of supplying for a short time a total load of about 40,000 kva at 11 kv, or ample power for a city of 60,000 people. This enormous moving load draws nearly twice as much current as a fault at the remote end of the trolley, which gives some idea of the problem involved in high-speed clearing of faults.

Protective Arrangement

Description of one of the schemes and its various elements will serve to indicate the method of solving this problem. The arrangement supplied by the Westinghouse Electric and Manufacturing Company consists primarily of an impedance relay of the high-speed type, and overcurrent elements. For longer trolley sections with heavy loads the overcurrent elements are replaced by an induction-type impedance relay, as shown in figure 10.

In general, the high-speed impedance relay, and the instantaneous current relay, where used, provide clearing for most faults, the two-cycle delay current or impedance element providing sequential tripping of the remote breaker for faults in the end zones. Thermal relays, matching the trolley heating characteristics, protect them against overload and make their full thermal capacity usable safely under any load cycle.

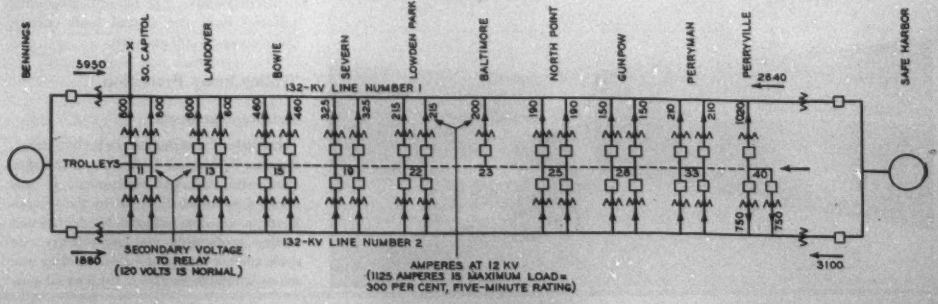
Impedance Element

The impedance element is of the balance beam type and operates in as little as $^1/_8$ cycle on 25 cycles. This high speed is made possible by use of double voltage restraint coils, differing in time phase and resulting in an almost uniform voltage restraint. Therefore, rise of the current-coil pull above the restraint is almost instantly detected by the relay element. Advantage is taken of the mutual reactance between trolleys which results in the impedance of 96 per cent of section length being only 80 per cent of the total section impedance. This characteristic, shown in figure 11, allows setting the relay balance point within 4 per cent of the end of the section and still retaining 20 per cent safety margin. Figure 11 is based on a four-track section, the ratios being less favorable as the number of trolleys decreases.

Current Directional Element

The impedance element is used with a current polarized directional element comparing the direction of trolley current with that flowing through the step-down transformer bank and having a tripping zone as indicated in figure 12 in order to select the faulty trolley. It is arranged to close contacts with no polarizing current provided the trolley current is sufficient.

Figure 7. Typical fault-current distribution under minimum conditions



Load Presetter

A load presetter used with the high-speed impedance relay compensates for the change in impedance caused by the presence of train loads on the trolley sections. An idea of the magnitude of this effect may be given by taking a typical seven-mile section which would have about $3^1/_2$ ohms impedance. A maximum trolley load considered is 3,000 amperes, which at an average potential of 11,000 volts would correspond to 3.67 ohms. Thus the impedance of the maximum load is roughly comparable with the impedance of the trolley section. For a fault at the one end of the trolley, the impedance looking into the other end of the trolley would be only 70 per cent as great if a maximum load were present uniformly distributed as it would be if no load were present. The load presetter compensates for this effect by providing additional voltage restraint proportional to the load.

Transient Shunt

Since instantaneous values are being dealt with, and since in an electrical system immediately subsequent to the occurrence of a fault, a d-c or transient component may be present whose magnitude is as much as the crest value of the alternating current, a large error in impedance measurement would take place unless some measure were adopted to discount this transient current. A transient shunt was developed for this purpose. This shunt removes the transient component of the short-circuit current both from the impedance element and from the overcurrent elements of the relay equipment, making it possible to set only for the symmetrical values of current which are predictable. But for this shunt, an element set to trip down to a balance point close to the other end of the section would trip well into the other sections in the event of an asymmetrical short circuit. Transient shunts have since been applied in other high-speed relay applications.

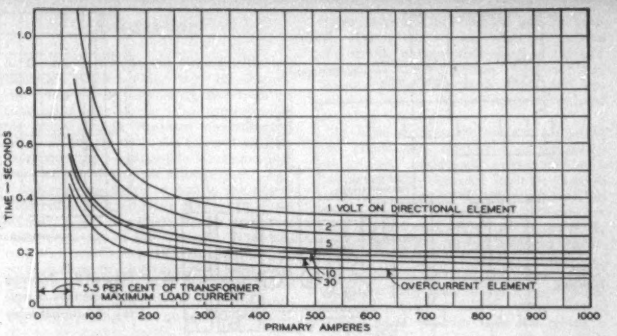


Figure 8. Supersensitive type CR reverse power relay characteristics

Note: Maximum load current = 1,125 amperes, five minutes. Normal secondary volts = 120

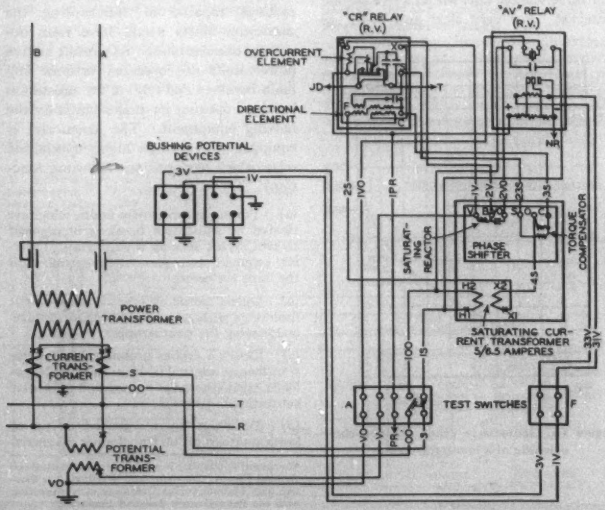


Figure 9. Typical reverse-power-relay connections at a step-down transformer station

High-Speed Overcurrent Relays

Overcurrent elements of both instantaneous and two-cycle time-delay types were provided. This permits instantaneous operation for all faults which are well above through fault plus load current. The two-cycle time-delay relay is set just above maximum load current, but below those currents which are caused by the combinations of load plus heavy through fault to the next section.

Induction-Type Impedance Relays

For longer trolley sections designed to carry heavy peak loads, discrimination between loads and faults becomes more critical and advantage must be taken of every available factor. The two-cycle-delay impedance relay balances E^2 against $EI \cos \theta$, and thus has maximum torque for current at a particular phase angle, which is adjusted to assist in selecting loads from faults. Thus loads may be carried of lower impedance than the relay setting provided the power factor is higher than during faults. In addition a thermal type of presetting is used which increases the setting in amount depending on the load current through the relay prior to a fault. Finally, the two-cycle delay provides selectivity with the breakers of other sections for faults outside of the protected section. This relay has inherent directional characteristics.

Bus Protection

After several stages of development including use of induction and instantaneous types of relays measuring differential current, the majority of busses have finally been protected by percentage dif-

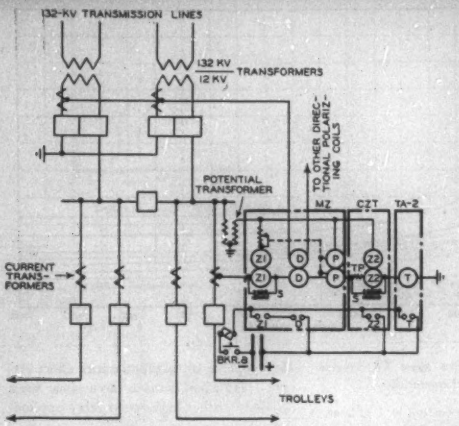


Figure 10. High-speed trolley relays—external connections

- *Z1* — First zone impedance element, *MZ* relay
- *D* — Current polarized directional element, *MZ* relay
- *P* — Load presetting element, *MZ* relay
- *Z2* — Second zone impedance element, *CZT* relay
- *T* — Trolley thermal element, *TA-2* relay
- *TP* — Thermal presetter
- *S* — Transient shunt

ferential relays type *CA-4*. These are relays having three restraining windings and one operating winding. For the trolley busses, the restraining windings are associated respectively with (1) incoming transformer feeders, (2) incoming bus tie, (3) outgoing trolleys. This relay results in extremely fast clearing of bus faults and is comparatively insensitive to through faults because of the large restraint. The same type of relay has been applied with excellent success to generator busses.

Transformer Differential Protection

The differential protection of transformers on a system which does not have high-voltage breakers at the station, is a somewhat difficult problem. It is obviously necessary to clear the entire transmission line, involving the opening of a large number of breakers, in the event of a fault involving the differential protection of a single transformer. For faults in the high-voltage winding of the step-down transformer amounting practically to line-to-line faults on the transmission system, the differential protection trips the low-voltage breaker and sets up a circuit for opening the high-voltage disconnecting switches after the fault has been cleared as indicated by the resetting of the type *CA* differential relay when the fault current is removed.

Out-of-Synchronism

At sectionalizing points located sufficiently near the electrical center between major generating stations periodic dipping of voltage forms an out-of-synchronism indication. A "dip counter" relay was developed consisting of a counting chain of telephone-type relays actuated by the type *AV* undervoltage relay and set to trip the system sectionalizing breakers for three voltage dips within a five-second interval. For very slow pull apart, or

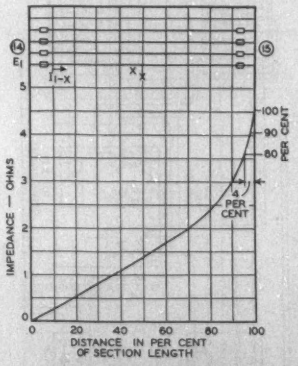


Figure 11. Impedance versus distance characteristic of a four-track section

$$Z = \frac{E_1}{I_{1-x}}$$

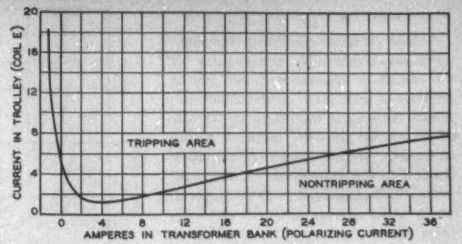


Figure 12. Tripping characteristic of trolley directional relay

out-of-phase conditions, overcurrent relays, operating on the totalized current of the two lines, produce simultaneous tripping of the sectionalizing breakers.

Undervoltage Sectionalizing

Considerable thought has been given to the confining of troubles to a particular section of the system by proper sectionalizing under certain conditions. In several instances low voltages have occurred due to various causes. This has resulted in loss of power and considerable disturbance to the system. Undervoltage relays have been installed at major sectionalizing points set to sectionalize the system automatically in event of the falling of voltage two-thirds of normal for a time adjustable between one and five minutes.

Motive Power Unit Relays*

As the trolley fault current may be as high as 50,000 to 65,000 amperes the use of high-speed circuit breakers on the locomotives capable of interrupting the maximum faults would have been decidedly uneconomical. As a result motive power units are operated without any main breakers and rely on the substation breakers opening for major faults on the moving equipment. The locomotive is equipped with a single highly specialized relay which performs the following functions:

(*a*). For major locomotive faults, which are cleared by substation breakers in one-half to two cycles, sets up a pantograph lowering sequence but prevents lowering until the fault is cleared.

(*b*). Opens motor switches to clear motor flashovers without causing a major outage, or lowering the pantograph.

(*c*). Closes a trolley grounding switch for transformer internal faults or sustained overloads, then lowers the pantograph only after substation breakers clear.

(*d*). Does not operate ground switch or lower pantograph on transformer magnetiz-

*Locomotive relaying is a joint development of the General Electric Company and Westinghouse Electric and Manufacturing Company in co-operation with the Pennsylvania Railroad Engineers.

ing inrushes in excess of fault currents. Such inrushes are sometimes encountered due to bouncing pantographs or when crossing trolley phase and section breaks.

Multiple-unit cars are equipped with a single device which performs less functions but which nevertheless is coordinated with the substation relaying, clearing faulty equipment from the trolley promptly after the substation breakers open and permitting prompt successful re-energizing of the trolley.

This general arrangement for clearing faults on motive power units has resulted in exceptionally good operation in the six years during which it has been in service.

Conclusion

Most faults occur on trolleys and transmission circuits, one fault being encountered per 20 miles of transmission line per year, and one fault per 1.17 miles of trolley per year. For the complete New York-Washington-Harrisburg system this will amount to approximately 55 transmission faults (grounds and short circuits) and 1,875 trolley faults per year. A large number of these are of a nature which clear when the breakers are opened so that the affected section may be immediately reclosed.

With the protective arrangement described, entirely adequate selectivity is obtained among different protective elements of the system under normal conditions and for certain abnormal system setups necessary for maintenance. In so far as possible, the designs and settings have been planned to give proper selective action under the innumerable abnormal conditions which may occur during emergencies, while still permitting full use of the power-supplying ability of all lines and apparatus.

Reference

1. A System Out of Step and Its Relay Requirements, L. N. Crichton. Electrical Engineering, October 1937.

Discussion

A. R. van C. Warrington (General Electric Company, Philadelphia, Pa.): Mr. Harder has given a very interesting paper on his company's part of the relay protection of the Pennsylvania Railroad electrification which recalls for us in the General Electric Company the considerable developmental work we also did on the same project.

Referring to figures 8 and 9, the supersensitive directional relay at the step-down stations uses a nonlinear circuit to ensure reliable torque at low voltage. This circuit was used in our 1928 single-phase reactance distance relay though we found later that greater amplification could be obtained by using a neon lamp to provide the saturating and detuning effect at normal potential, due to its sharper cutoff.

Over 80 per cent of the trolley breakers are of General Electric manufacture equipped with impulse trip, for one-cycle interruption. Backing up the impulse trip are the *CEX* relays which, in addition, take care of faults below 1,800 amperes. These relays contain two induction-cup-type units whose contacts are in series. One unit is a directional impedance unit and the other is a directional admittance unit. This peculiar combination was necessary to produce a combined characteristic which would fit in between load and fault conditions. The settings of the two units correspond to the section length. The relay operates in one cycle to open the holding coil circuit of the breaker so that it closely backs up the impulse trip. The dying away of the holding coil flux and the opening of the breaker brings the total clearing time within three cycles.

The *CEX* relay is relatively insensitive to transformer energizing transients because the operating torque of the directional impedance unit is a product of the current flux and the flux of the tuned potential circuit. It does not require a transient shunt because the d-c component produces no torque in induction relays.

The *CEX* relay gives positive directional action even on bus faults which produce zero potential because the polarizing potential winding of the directional impedance unit is tuned with a series capacitor with which it continues to oscillate for several cycles after the line voltage goes to zero. Mr. Harder did not say what precautions of a similar nature were taken in the corresponding Westinghouse Electric and Manufacturing Company directional impedance relay to ensure reliable directional action on bus faults.

In some sections the current, potential, and phase-angle conditions during maximum traffic conditions correspond to a fault within the section. In order to avoid unnecessary tripping of trolley breakers, the *CEX* relays are normally set high and are only dropped to their proper values if the rate of rise of the current indicates a fault. In order to distinguish rapid rate of rise the line current is rectified and then supplied to an auxiliary relay which supervises the protective relays. Under normal conditions the rectifiers produce only d-c which is blocked by a transformer. On the other hand, a sudden rise of current caused by a fault produces a corresponding rate of increase in the rectifier output and this increase in turn creates an impulse of current in the secondary of the transformer which operates the supervising relay.

These are a few of the many interesting problems which were solved for this unique application.

C. Romanovsky (nonmember; General Electric Company, Philadelphia, Pa.): E. L. Harder's paper on relay protection for a railroad system is of great benefit to engineers interested in a-c railroad electrification.

Other relays than those described in Mr. Harder's paper have been supplied by the General Electric Company for the solution of numerous difficult problems of system protection on the Pennsylvania Railroad electrification projects.

Among these were relays of very strict requirements for the differential protection of the 132-kv underground oil-filled cable at Baltimore and Washington. These relays must stand 5,000 amperes primary for five seconds and operate on faults as low as 30 amperes primary.

The relays operate over a two mile run (average) of number 10 pilot wire, and are meeting the following requirements:

The relays must not operate on:

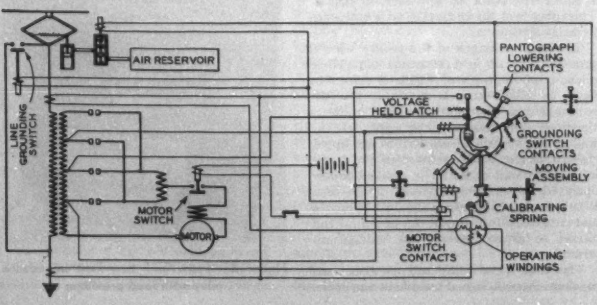
A.	Five-minute load.....	up to 300 amperes
B.	Through short circuit...	up to 5,000 amperes
C.	Through ground fault..	up to 800 amperes
D.	Charging current.....	up to 20 amperes

The relays must operate on:

A.	Short circuit in cable.....	from 30 to 5,000 amperes
B.	Ground on cable.....	from 30 to 800 amperes

The relay operates on a sensitive percentage differential principle. It contains an operating and a restraining circuit. The current transformers at the two ends of the cable are differentially connected with respect to the operating coil so that on a fault in the cable, current will flow in the operating coil and thus operate the contacts. During an external fault, the current flowing in the secondaries of the current transformers and in the restraining coil opposes the effect of any operating current which may result from slight difference in the secondary currents of the current trans-

Figure 13. Schematic diagram of locomotive relay



formers. This restraining action prevents operation on through faults.

For the New York zone, where direct current is superposed on a-c apparatus due to common rail return circuit, relays were developed to prevent opening motor-operated disconnecting switches when more than 25 amperes alternating current with superposed 750 amperes direct current is flowing in the circuit and be able to withstand short-circuit currents of 50,000 amperes.

In order to reduce the cost of electrical equipment in large station areas, groups of low-interrupting-capacity normal-speed breakers are used for the isolation of faults on yard and passenger station feeders. Each group of from two to five breakers is fed by a high-speed high-interrupting-capacity (master) breaker which clears the fault. The high-speed breaker is relayed similar to other trolley breakers for discriminating between load and fault currents and for selective operation.

A relay was developed for selecting the faulted trolley before the master breaker opens so that when this breaker has cleared the circuit and the current through the low-interrupting-capacity breaker on the faulted trolley has fallen to a safe value, the relay permits the low-interrupting-capacity breaker to open. After the opening of the low-interrupting-capacity breaker, the relay closes the master breaker, and thus restores service on the unfaulted trolleys.

The operation of a great number of trolley-sectionalizing disconnecting switches offered an interesting problem. They were to be operated from distances up to five miles by 110-volt 100-cycle power taken from 6,600-volt signal lines at points near the disconnecting switches. The current through the control cable was limited to 0.15 ampere. Control and position indication of the disconnecting switches was to be accomplished over the smallest number of wires. Undesirable operation and false indication of switch position by induced currents during short circuits on the trolley system was to be avoided. Hazard of shock to operators and maintenance men was to be removed.

A relay and control scheme was developed using only four wires for each switch.

Small 110/220-volt insulating transformers with midpoints grounded are used rather than impedance coils. With this scheme high induced potentials cannot stress the insulation of control devices.

L. N. Crichton (Westinghouse Electric and Manufacturing Company, Newark, N. J.): There is an enormous amount of power available on this system so that the relays and circuit breakers must be capable of safely withstanding very heavy short-circuit currents. On the first units of this electrification the anticipated loads were small enough and the sections of trolley wire were short enough so that the load current never exceeded the minimum short-circuit current. It would, therefore, have been possible to protect these sections by means of instantaneous overcurrent relays set to operate on a high current and time-limit overcurrent relays set to operate on a low current. Such relays were actually installed and in addition instantaneous impedance relays were installed to secure maximum possible simultaneous clearing of faults.

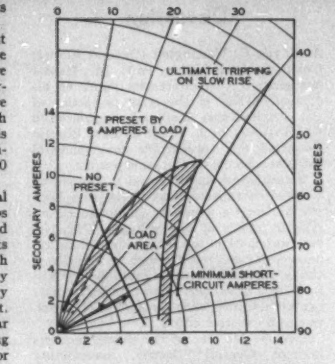


Figure 1. The load characteristics and the tripping point of the type CZT impedance relay for long trolley section at varying phase angles and load conditions

Now the loads are heavier and the newest electrified sections are much longer so that the load current under some conditions is greater than the short-circuit current. The anticipated loads and minimum short-circuit currents are shown in figure 1 of this discussion. This curve also shows the tripping characteristics of the time-limit impedance relay mentioned by Mr. Harder. It will be observed that the relay will trip if the minimum short-circuit current is applied when no load exists. If a load has existed for several seconds, the relay will trip when an additional sudden increase in current is applied. Finally, the relay will trip if current is either gradually or quickly added above the values shown on the curve at the extreme right. This adjustment differs for every different length of line.

This relay has an adjustable time limit of two cycles or more and is intended to protect only the far end of the trolley wire. A photograph of this relay is shown in figure 2 of this discussion. The thermal element which increases the setting of the relay when the load comes on is the nickel wire shown at the front of the slider. This picture shows the complete relay except for an external resistance in the potential circuit and a shunt reactance in the current circuit. This relay is of the induction type and is inherently directional.

The greater length of the trolley wire is protected by an instantaneous impedance relay, a photograph of which is shown in figure 3. This relay is not inherently directional and, therefore, contains a directional element shown in the upper left, as well as the impedance element in the upper right, and the load presetter in the lower left. This load presetter is a small motor operated by the volt-amperes in the line. When the load increases, this motor moves and cuts resistance out of the potential coil circuit so as to increase the voltage restraint.

This high-speed relay and its associated breaker clears the usual trouble in one cycle. This requires that the relay cannot have more than one-fourth cycle in which to operate and sometimes the operation is much faster than that. The result of this fast operation is that even the heaviest of short circuits cannot be observed at the generating stations and it is seldom that any burning can be found on the trolley wires. From the figures given in Mr. Harder's paper it can be calculated that the average section of trolley wire has six short circuits per year, about five of which are cleared by the high-speed relays and one by the two-cycle time-delay relay.

It was difficult to design a relay to work accurately at this high speed because of the transient in the circuit. Although this transient has practically disappeared in two cycles, it is of enormous consequence during the first one-fourth cycle when the relay must complete its work. The problem was solved by the invention of the transient shunt, the use of which has since been extended to other types of high-speed relays.

D. R. MacLeod (General Electric Company, Erie, Pa.): Mr. Harder's presentation of the relay protection of the power supply for the Pennsylvania Railroad electrification brings out the interesting contrast between the comparatively leisurely manner (seconds) in which a high-voltage transmission fault is cleared and the get-rid-of-it-quick (cycles) attitude toward trolley faults. The high level of insulation adopted for the 132-kv and 44-kv lines and the adequate ground wire and counterpoise protection is one justification for this philosophy. The ability to isolate any section of transmission between substations with only temporary interruption of power to these substations, even where only one line is available, is another justification. There were, of course, additional reasons for these engineering decisions since relaying was not the dominant factor in designing this transmission line and trolley system. While the trolley is provided with a high level of line insulation and is shielded by the transmission circuits the data given in this paper show that 97 per cent of the faults occur on the trolley. This relation between transmission and trolley faults was expected when the system was designed.

The devices used in the General Electric

Figure 2. Type CZT time-limit impedance relay with load presetting

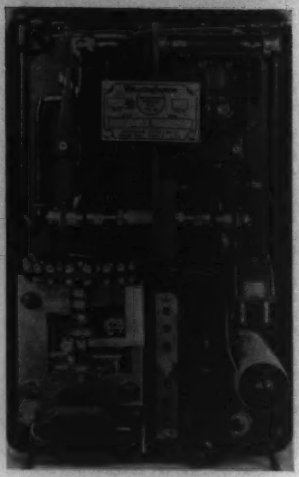


Figure 3. Type MZ high-speed impedance relay with load presetting

trolley relaying scheme are described in the discussions presented by Messrs. Romanovsky and Warrington.

There are important differences between this system of relaying and that described by Mr. Harder. Our approach to the problem has been based to some extent on theoretical studies such as Mr. Harder has described but we have given even greater consideration to experiences in the field. The majority of trolley faults occur in connection with the operation of the rolling stock and therefore we have given particular attention to the troubles which develop on these equipments. Our relaying has been designed to allow the greatest possible freedom in the design of the rolling-stock equipments which are always handicapped by space limitations.

The control schemes on different groups of locomotives differ in detail. On one group it is possible for one locomotive to have the impedance characteristics of three locomotives for an appreciable time before the operation of the ground switch. The distinguishing characteristic is however the low power factor under this particular condition. When the ground switch operates this "load" goes to zero and the impedances measured by the trolley relays are the same as if the load had not been present. If the locomotive was operating double headed the fictitious load would be equivalent to four locomotives accelerating and power factor will be entirely different from what may be expected with four normal locomotives. After the grounding switch closes there is a sudden increment of current due to the fact that the locomotive impedances are reduced to zero and this increment is always in excess of the notching increments on any of the rolling stock equipments.

Other examples of this general type based on actual experience in the field might be recited but it serves to show why our relaying system does not attempt to take advantage of presetting the relays in accordance with the characteristics of the load.

Mr. Harder claims that the transient shunt makes it possible to set the high-speed relays only for the symmetrical values of current which are predictable. Our studies of the various types of energizing transients which can occur on a locomotive load show a wide variety of wave fronts which would require a complicated network to handle. The symmetrical components of these transients are not predictable as they are complicated by the induction-motor load on the secondary of the locomotive. There is some inherent shunting of the transient in the impulse scheme but we do not take advantage of it. No shunting is necessary with our impedance relay. The settings of the impulse trip have been determined by field experience during the ten years that it has been in operation on this electrification.

Our first line of defense is the impulse trip. This scheme was originated by J. W. McNairy and is described by him in AIEE TRANSACTIONS, volume 47, October 1928, page 1276. The second line of defense is the distance relay described by Mr. Warrington which can be set to cover the entire distance between substations. It is not desirable to take advantage of the mutual impedance between trolleys (see figure 11 of Harder's paper) because this mutual may not be there when it is needed most and it is possible to visualize conditions when it is in the wrong direction. On the Harrisburg electrification a few rate-of-rise relays were provided for those sections of the railroad where it was feared that abnormal operating conditions might show that it is desirable to have an additional means of discriminating between a load and a fault. The experience gained with these equipments will be of value in working out adequate protection for the trolleys as substation spacings are increased. However, it should be noted that the trend of operation practices on this electrification is in the direction to make the relaying problem considerably easier than was first visualized.

An important consideration in distance relaying is the variation in the impedance characteristic of a locomotive with variation in trolley voltage. It may be shown from a consideration of the characteristics of the a-c series motor that for a given tractive effort, field connection, and power factor the impedance as measured at the pantograph of a locomotive varies as the square of the applied voltage and that for a given tractive effort the minimum impedance varies directly as the applied voltage. The minimum impedance of two locomotives pulling the heaviest freight train which we know of from Enola (across the river from Harrisburg) to Waverly, N. J., is of the order of ten ohms at approximately 80 per cent power factor with a trolley voltage of 11 kv. If the freight train is half the size but has two engines on it to get motive power to the other end of the line, the minimum impedance will probably be the same as with the heavier train. The locomotives in passenger service present the real problem. A train which could operate with one engine may be double heading and the engineer may elect to accelerate rapidly. The minimum impedance may be seven ohms and the power factor near 85 per cent. As the train speeds up to running speed in passenger service, the power factor goes above 90 per cent and the impedance increases. The impedance of the double-headed passenger train at the power factor corresponding to the angle of the line will probably be the same as that of the heavy freight train. This impedance is, of course, much greater than the minimum impedance. In the case under consideration it would be approximately 12.5 ohms. If the voltage falls to 8,500 volts the impedance of the train at the power factor corresponding to that of the line may be 7.5 ohms. Because of the rapid acceleration of the passenger train the highest values of current are only experienced for a matter of seconds so that the trolley is not overheated. The distribution of passenger trains running with several sections is considerably closer than is usual in freight operation. It is, of course, difficult to predict what the groupings of trains will be under abnormal conditions of operation and therefore the railroad engineers specified certain conditions as a basis for working out the relay problem. The General Electric Company's system of trolley relaying was given the greatest flexibility that modern relaying permitted as it was recognized that future developments might prove that the specified conditions were inadequate.

W. A. Lewis (Cornell University, Ithaca, N. Y.): Certain phases of the paper by Mr. Harder appear to justify further amplification and emphasis. It is stated in the paper that prior to the advent of the a-c network calculator, the short-circuit currents were determined analytically. It has been the practice for a number of years on a large number of systems to use the d-c calculating board for the determination of short-circuit currents, and some question may arise as to why the d-c calculating board could not be used in this case. The d-c calculating board introduces the fundamental assumption that the phase angles of the various impedance elements entering into the network are so nearly the same that they may be assumed equal without introducing appreciable error in calculation. In this case, the frequency is 25 cycles, with the result that the reactance components are less than half of what they would be if the same circuit elements operated at 60 cycles. Because of the relatively large resistance components in the transmission circuit elements, the ratio of reactance to resistance is quite low at this frequency, and the phase angle of the circuit element is therefore relatively small, in the order of 45 degrees. On the other hand, the phase angle of the transformer elements remains quite high, in the order of 80 degrees or more, with the result that the phase angle of the transformer elements is much greater than of the line elements. For a fault in any given location there are numerous parallel circuits involving the step-down transformers in the several substations, and the division of current between these parallel branches is important in the application of the relays. Because of the wide phase-angle difference just described, it was not possible to obtain sufficient accuracy in a solution made on the d-c calculating board, and accurate representation on a miniature system was therefore not possible until the a-c network calculator became available.

Another feature deserving of mention is the mutual impedance between the several parallel trolley-rail circuits, due to inductive coupling between the parallel trolleys, and to the common use of the rail and earth in the return circuit. Mutual impedances of this character are difficult to represent on a d-c calculating board when the number of parallel circuits exceeds two, as it does on the Pennsylvania Railroad when more than two tracks are involved. This problem can be handled readily on the a-c calculating board by the use of mutual transformers which have previously been described.

The description of the protection of the extensive power supply system for this railway invites a comparison with the relaying of public utility systems. Two important differences may be noted between the two different forms of power supply. With the railway system, the load is distributed along the trolley circuits, and moves rapidly from one location to another. This means that the currents and the impedances measured by the relays for a short circuit in a given location will vary considerably depending upon train location and the load drawn at the time the fault occurs. This is in contrast with the public utility system in which the major load is almost always drawn from fixed substation locations usually at bussing points, and does not move rapidly from one place to another. The so-called "load presetting device" which recalibrates the relays as a function of the load just prior to the fault is an unique and interesting method of overcoming the problem encountered.

The second notable point of difference is the use of high-voltage lines with the large number of substations tapped in without the use of high-voltage breakers at any of the substations. Although there has been a certain tendency to eliminate the high-voltage breakers in the power system, it has never been practiced to anything like the extent utilized by the railroad. The high speed of protection obtained with this layout, which appears very complicated to the relay system, is quite notable. The development of the very sensitive reverse-power relays indicates what can be done when the necessity arises. The absence of high-voltage busses makes possible the very unique use of balanced voltage relays for the protection and isolation of ground faults.

It is also interesting to note the developments in the railway field which have found application in the utility field. The most notable of these is the use of the high-speed balanced-beam type of impedance relays. Although the principle was not new at the time, the railway installation represented the first installation in the United States of the high-speed impedance relays operating on this principle. Impedance relays operating on the same principle are now the accepted means of providing the highest speed phase-to-phase protection on utility systems, being used in the majority of distance relays, and being the backbone of the carrier-current relay system which has found the greatest favor in the last few years.

E. L. Harder: The supplementary information contributed by the several discussers on the trolley relays is the most valuable addition, making the paper a rather complete description of the over-all relay system from generator to motive power equipment. The paper had covered the protection of eight main system elements but had described only the Westinghouse form of the trolley relay protection. The discussion completes the picture of this particular element of the relay system. Strangely enough, however, the high-voltage system represents by far the more difficult and complicated relay application problem. Certain questions and points are raised by the discussers requiring additional information which is given in the following.

Mr. Warrington states that the *CEX* relay operates in one cycle. We assume that this refers to its operating time for faults close to the relay since if it operated with this speed for faults at the remote bus it would trip also for faults on that bus or in the next section. The delayed relay time mentioned in the paper for the *CZT* time-delay impedance relay is given for fault at the remote bus.

He has requested to know how the Westinghouse company has solved the directional-relay problem which exists on a single-phase system susceptible to solid faults. A current polarized directional relay was used in which the totalized current of the step-down transformer supplies the polarizing element of the relay as shown in figure 10. Thus voltage is not required on the directional element. Its characteristics are shown in figure 12 of the paper.

Mr. Romanovsky describes the protection of the oil-filled cables and lists the setting requirements. It would of course have been interesting to go into this detail for other of the relays but the space limitations of the Institute paper do not permit. He has described the manual remote control of sectionalizing switches. We fail to see what connection this has with a paper on protective relaying.

In Mr. Crichton's discussion, figure 3 shows the current polarized directional element mentioned above. His explanation of the difference in the importance of transient shunt for a fractional cycle relay as compared with a relay operating in one or two cycles is particularly significant.

Mr. MacLeod mentions that the normal clearing times (one or two seconds) used on the high-voltage system are justified by the ability to sectionalize and obtain only temporary interruption of power to substations. Out of 61 step-down substations only three received power from a single line and these three have adjacent stations fed from both lines with consequent trolley feed. Therefore in almost all cases faults can be relayed out without interfering with loads at all. At the three stations fed from a single line the question of whether the line is cleared in a cycle or a second does not affect the duration of time required to sectionalize faulty line and re-energize the station. It does not appear that the ability to isolate any section of transmission has anything to do with the justification of normal-speed relaying. The matter of prime importance is that the clearing of high-voltage faults does not interrupt power to the trolley and consequently higher speeds are not essential.

He questions the ability of the transient shunt to make possible setting for symmetrical component of current only and mentions different wave fronts of locomotive inrush current. The high-speed impedance-relay setting is actually based on the symmetrical component of current and the relay is set to produce simultaneous tripping over 80 per cent of the section length. In view of the large number of trolley faults (one per mile of trolley per year) this is unquestionably proof of the efficacy of the transient shunt. There is a disagreement in view of the transient shunt in its function. Mr. Warrington assumes (correctly) that the transient shunt removes d-c component and states that his *CEX* relay does not require a transient shunt because the d-c component produces no torque in induction relays. Mr. MacLeod states that their studies "show a wide variety of wave fronts which would require a complicated network to handle." This would seem to require some further explanation of the transient shunt action.

If a sine-wave voltage is impressed on a resistance-inductance circuit at some particular instant of time a current flows which has a d-c component dying out with a certain time constant L/R. If this process is reversed and the same current (except in secondary terms) is passed through the same resistance and inductance (or values proportional thereto) the sine-wave voltage (except in secondary terms) will be reproduced, without any d-c component. If then this voltage were used to supply a pure resistance relay the relay current would be proportional to the symmetrical component of line current only. The exact theory upon which the design is based takes account of the actual relay burden in determining the correct proportions. However, the foregoing picture is a quite accurate representation of what occurs. It is apparent that the shunt is effective right from the start and hence usable on a relay which has an operating time of less than one-fourth cycle. The time constant of the d-c transient on the Pennsylvania Railroad trolley circuits is about one-third cycle for fault at the remote end of the trolley. The transient is therefore not of much importance anyway on the *CEX* relay which Mr. Warrington states operates in one cycle. We would expect it to have some effect on the impulse trip which operates in a fraction of a cycle. It is possible to obtain a much larger zone of simultaneous high-speed action of breakers at both ends of the line through the use of the transient shunt.

Mr. MacLeod states that it is not desirable to take advantage of the presence of the paralleling trolleys because they may not be there when needed. Mr. Boehne pointed out in his oral discussion that advantage is taken of the paralleling trolleys in the General Electric scheme in preventing the impulse trip from operating for faults at the remote bus. The same objection applies in both cases. Also, in both cases the answer is the same. The advantages which accrue under all normal and reasonable abnormal conditions are well worth suffering the slight adverse effects under extreme abnormal conditions.

Mr. MacLeod also suggests that the mutual might be in the wrong direction. This seems like an unnecessary suggestion to make without good cause. For a fault near the remote end of a trolley, which is the only condition under which mutual impedance between trolleys affects the relay one way or the other, currents flow in the same direction in all the trolleys, namely, toward the fault. Thus the currents in the

Fiber Glass—An Inorganic Insulation

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MEMBER AIEE

FIBER-GLASS textiles have achieved considerable importance in the field of electrical insulation since their introduction to industry a few years ago. Design engineers are finding in them a solution to special problems which heretofore had been solved only inadequately or temporarily at best.

It is a well-known fact that the output rating of a piece of electrical equipment is limited first of all by the temperature its insulation will stand without excessive deterioration. The commonly used types of organic insulation, that is, cotton, silk, linen, and paper, rarely permit a rated temperature rise greater than 55 degrees centigrade over an ambient of 40 degrees centigrade. Where higher temperatures were unavoidable, asbestos has been used if the attendant space factor was not prohibitive and the low tensile and dielectric strength were not of great importance. Mica in many different forms—as the outstanding class *C* insulation—has been used extensively, but the lack of mechanical strength and the high cost have imposed sizeable limitations.

Another never-quite-solved problem has been that of moisture absorption in fibrous insulation. And no amount of treatment or impregnation has as yet effected a perfectly moisture-proof flexible insulation that also is heat and oil resistant.

It is in the providing of a more satisfactory solution to these two specific problems of heat and moisture resistance that fiber-glass insulation, up to the present time, has contributed most extensively. Other characteristics such as chemical stability and mechanical strength coupled with heat and moisture resistance are proving increasingly valuable. Concrete examples of the resistance of fiber glass to the effects of corona together with outdoor moisture conditions have come to light recently in connection with its use on neon-sign lead wire.

Glass as an electrical insulator has been used for many years, but only comparatively recently has it achieved flexibility. In so doing it has become the first totally inorganic textile—one whose characteristics observed in the laboratory and in operation have proved it to be as good as, and in most cases superior to, other fibrous materials used for electrical insulation.

The fibers are pure glass and the fundamental process which converts the original batch into molten glass is the same as that used in making milk bottles or window panes. Some of the batch constituents are also the same. The important difference between ordinary glasses and those used in making electrical insulation is that the latter contain no monovalent substances and are alkali free. To be alkali free is an essential property because alkali leaches to the surface, thus presenting an ionizable salt which, under conditions of high humidity, decreases the insulation resistance considerably. This phenomena is aptly illustrated by tests on a low-alkali glass tape and a similar one which was made of alkali-free glass. After 72 hours in a constant relative humidity of 90 per cent at 100 degrees Fahrenheit, the insulation resistance of the alkali-free glass was 40 times that of the low-alkali glass.

The data herein are presented to indicate some of the more important properties of fiber glass and some of the fundamental reasons for its acceptance as an answer to specific problems in the field of electrical insulation. These data are discussed in considerable detail and comparisons are made to other commonly used types of insulation.

Glass fibers are produced in two distinct types, staple length and continuous. The former are comparatively short fibers from 8 inches to 15 inches long and approximately 0.00025 inch in diameter. Fabrics made from these short fibers resemble cotton or woolen ones. The continuous fibers, as their name implies, are produced in continuous lengths limited only by the size of the spools upon which they are wound. They average 0.0002 inch in diameter.

The staple-length forming apparatus consists mainly of a small electric resistance furnace, a steam blower with nozzles for producing high-speed steam jets, a chain conveyor, and a packaging machine. One-third-ounce glass marbles are fed into the top of the furnace automatically one at a time, and are melted. The furnace is made of high-temperature refractory material with the exception of the bottom which is made of a precious metal alloy. The molten glass passes through small orifices in the alloy from which point the resulting filaments are blown downward onto a drum-type conveyor by high-velocity steam jets. Lubricating oil is sprayed onto the fibers as they are being blown downward onto the chain in order to minimize the interfiber

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adjacent trolleys acting through the mutual impedances increase the effective impedance of the relayed trolley which is as desired. When the remote breaker opens, if the fault is between the relay and the remote station, currents in the other trolleys reverse and flow toward the relay and thence over the faulty stub end trolley to the fault. Again this is also desired. The effective impedance is lowered by the mutual and the high-speed impedance-relay element which was set short of the remote bus when all breakers were closed is actually able to clear a fault at the remote end of the trolley as soon as the remote breaker opens, by taking advantage of the reversal in current direction in the parallel trolleys. This covers all of the possible conditions. Thus the mutual voltage drop is sometimes in the reverse direction but never in the wrong direction as Mr. MacLeod suggests.

The implication that variation of locomotive impedance as the square of line voltage depends on series-motor characteristics, is somewhat misleading. Given *any* type of load operating at a given voltage on the secondary of the transformer; raise the primary voltage, and change the transformer taps so that the secondary voltage is the same as before; the impedance (ratio of voltage to current) as viewed from the primary side of the transformer will have increased as the square of the voltage. This is for the simple reason that the turns ratio increases directly as the voltage. Impedance varies as the square of the turns ratio.

The really important thing is that the series motor behaves like an impedance at all, that is, that when the applied voltage is suddenly raised or lowered, current raises or lowers proportionally in a negligible part of a cycle. For example, if the applied voltage falls to zero the motor current falls to zero so fast that the difference in time is not distinguishable on a film with cycles spread out to one inch. This would not be the case at all with synchronous motors for example, which would feed heavy short-circuit current in the trolley when it is faulted.

Mr. Lewis has compared the railway transmission system with conventional power-system practice. His broad experience in both fields makes this comparison of particular value.

Table I. Breaking Strength in Pounds (Minimum of at Least Five Readings on Each Sample) of Staple- and Continuous-Fiber Alkali-Free Glass Tapes at Room Conditions

Width (Inches)	Thickness (Inch) 0.010	0.015	0.020	0.025
Staple				
1/4	59	85	105	*
3/8	68	108	119	132
1/2	110	158	183	231
3/4	150	167	245	290
1	182	250	305	346
1 1/4	268	298	360	400
Continuous				
1/4	70	*	186	
3/8	91	*	265	
1/2	133	285	346	
3/4	220	322	440	
1	280	494	595	
1 1/4	*	610	850	

* These sizes not available for test.

friction during the subsequent processing. Being prevented from blowing off the chain by air suction beneath it, the mat of fibers is then drafted into a single sliver by winding the latter on a two-inch-diameter paper tube whose linear velocity is greater than that of the drum conveyor. The tubes of sliver are then placed on textile spinning machines where the yarn is spun in the same manner as cotton or wool yarn.

The continuous process differs from the staple process mainly in the manner in which the fibers are drawn from the furnace. Here no steam jets are used. The fibers (102 of them) are drawn together into a single filament and are pulled down from the furnace mechanically by winding on a bakelite tube fastened to a spindle revolving at high speed. Lubrication is accomplished by passing the filament over an oil-soaked felt pad. The filament made up of 102 individual fibers is wound on the tube at the rate of 6,000 feet per minute. (One marble will produce over a mile of the filament or about 120 miles of individual fiber.) At this point the product is ready for the twisting operation in the textile fabrication sequence. The yarn and fabrics produced from continuous fibers resemble silk or rayon in appearance.

In general, staple-fiber products are preferable where a heavy type of insulation is required. Continuous fabrics have their advantage where space factor, impregnating qualities, or appearance, are of primary importance.

Tensile Strength

This is one of the more important properties of electrical-insulation textiles and perhaps the most important mechanical one, not only because of the obvious reason, but also because it provides an excellent means of measuring the effect of other test and operating conditions upon fibrous materials. For instance, the effect of heat, acids, weathering, etc., may be evaluated by noting the corresponding change in tensile strength.

Glass fibers of diameters such as are used in making textiles for electrical insulation have extremely high breaking strength. The value for individual fibers of the order of 0.0002 inch in diameter has been shown to be in excess of 1,000,000 pounds per square inch. No other textile fiber approaches this figure. Tests also show that woven glass fabric is stronger than other textile fabrics.

Table I shows the minimum breaking strength of some of the standard staple-fiber and continuous-fiber alkali-free glass tapes used for electrical insulation.

Table II shows the breaking strength of standard 0.010 inch by 1 inch staple-fiber glass tape after subjection to different temperature cycles simulating those which a piece of electrical equipment might encounter under severe operating conditions. It will be noticed that after a temperature cycle of 500 degrees Fahrenheit for 30 minutes each day for ten consecutive days the tape still retained 79 per cent of its original strength. After 400 degrees Fahrenheit for 30 minutes, its strength even increases slightly, probably due to the decreased viscosity of the processing oils permitting a greater equalization of stress among the individual fibers.

One accepted test of heat-resistant insulation is to subject it to a temperature of 300 degrees centigrade for five minutes. A series of these tests has shown that continuous-fiber glass tape retains from 87 to 92 per cent of its original strength and staple-fiber tape retains from 85 to 95 per cent. Similar tests showed that underwriters' grade asbestos tape loses approximately 46 per cent of its original strength. (After subjection to this temperature, cotton tape did not have sufficient strength to permit tensile strength tests.)

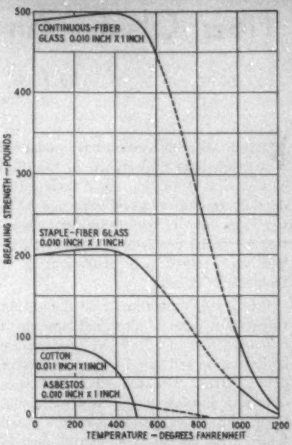

Figure 1. Effect of heat on tensile strength of electrical tapes

The effect of heat on the tensile strength of asbestos, cotton, and fiber-glass tapes is shown graphically in figure 1. Each curve represents averages of numerous determinations obtained over a period of a year.

Data below 600 degrees Fahrenheit were obtained by heating the tape in an electric resistance oven for at least 24 hours in each case and then breaking the specimens in a pendulum-type tensile-strength tester, the average of five good breaks being used to determine each point. Above 1,000 degrees Fahrenheit the data were obtained by heating the tape in a small electric furnace and then determining the breaking strength in the same manner. No data were obtained between 600 degrees and 1,000 degrees; hence that portion of the curve is dotted. Throughout this series of tests, the maximum deviations from the mean were +10.5 per cent and −20.5 per cent.

Table II. Breaking Strength in Pounds of 0.010 Inch by 1 Inch Staple-Fiber Tapes After Subjection to Different Temperature Cycles Simulating Those Which Might Be Encountered by Electrical Equipment in Operation

	Original Conditions	400 Deg F for 30 Minutes	400 Deg F for 30 Minutes Each Day for 10 Consecutive Days	500 Deg F for 30 Minutes	500 Deg F for 30 Minutes Each Day for 10 Consecutive Days
	234	240	180	180	167
	182	187	198	185	157
	205	239	195	200	165
	213	200	195	190	176
	218	229	184	205	166
Average	210	319	190	194	166

Table III. Flexing Endurance

Samples 0.010 Inch by 1 Inch by 17 Inches

	Yellow Varnished Cotton Cloth	Yellow Varnished Glass Cloth
As received	2,100	2,700
After 280 deg F 24 hours	12,000	72,000
After 350 deg F 2 hours	4,500	80,000

These curves show that glass tape is from 2 to 20 times as strong at room temperature as similar tapes made of other commonly used fibrous materials. The strength of glass tape does not diminish appreciably up to 600 degrees Fahrenheit and after 24 hours at 800 degrees Fahrenheit, it still retains half of its original strength.

Resistance to Abrasion

There is a wide variation of opinion as to what constitutes a proper test for the abrasion resistance of textiles. For this reason no conclusive tests have been made on fiber-glass fabrics. Tests have been made, however, on untreated and on impregnated tapes by sliding a five-pound steel weight (the bearing surface being knurled and on one-half inch radius) back and forth on a one-inch-wide specimen stretched over a steel plate. Revolutions of the reciprocating arm which drove the weight were counted until electrical contact was made between the five-pound weight and the steel plate.

With this method of test, untreated fiber-glass tape appeared to be on a par with equivalent asbestos tape, but weaker than cotton. The samples were not entirely comparable, however, due to the more open weave of the asbestos and the glass. Similar tests on impregnated tapes showed the glass tape to be the strongest of the three.

One or two manufacturers have said that some difficulty has been experienced due to the cutting of glass on sharp edges of metal during coil-winding operations. Others say that with reasonable care on the part of the workmen no difficulty is encountered.

Flexing Endurance

Insulation for many applications requires a considerable degree of flexibility and at the same time endurance to flexing, both during the treating and impregnating processes and during application on or in the finished equipment.

That glass fibers are spun, twisted, and woven on standard textile machinery into fabrics as thin as 0.002 inch is some indication of their flexibility. Using the test apparatus described below, five samples of standard 0.010-by-1-inch untreated continuous-fiber glass tape broke after an average of 26,500 flexes. Table III shows the number of flexes required to break one-inch-wide samples of 0.010 inch thick commercial yellow, varnished, cotton, and glass cloths after various heat treatments.

In making these tests one end of a sample 17 inches long was attached to a clamp fastened to the rim of a pulley 13 inches in diameter. The other end of the sample was attached to a stationary clamp placed below the pulley clamp so that

Table IV. Dielectric Strength of Standard Unimpregnated Cotton, Asbestos, and Fiber Glass Tapes

All Samples 0.015 Inch by 1 Inch Nominal Except the Cotton Which Was 0.011 Inch by 1 Inch

	As Received				Washed*			
	Average Thickness (Inch)	Volts Per Mil			Average Thickness (Inch)	Volts Per Mil		
		Maximum	Average	Minimum		Maximum	Average	Minimum
Cotton	0.0121	99.5	94.5	82.9	0.0156	92.5	88.5	86.3
Asbestos	0.0151	66.2	58.3	45.0	0.0201	57.8	51.2	42.9
Continuous-fiber glass	0.0168	98.0	94.4	92.1	0.0135	107.2	97.3	92.5
Staple-fiber glass	0.0162	98.9	92.3	83.5	0.0152	102.3	99.6	95.7

NOTE: Tests were made by the short time method at room temperature of approximately 80 degrees Fahrenheit and 65 per cent relative humidity using one-fourth inch diameter brass electrodes and increasing voltage at the rate of 500 volts per second to breakdown. Each value is maximum, average, or minimum of ten readings of breakdown voltage divided by the average of ten readings of thickness.

* Samples were washed by boiling for 15 minutes in water containing 0.5 per cent soap and 0.2 per cent soda ash by weight; then dried in an oven at 225 degrees Fahrenheit for 30 minutes and conditioned at room conditions (approximately 80 degrees Fahrenheit and 65 per cent relative humidity) for at least 96 hours.

Table V. Dielectric Strength of Varnished Fiber-Glass Cloth as Compared With Standard Varnished Cotton Cambric After Short-Time Heat Treatment

	Average Thickness (Inch)	Volts per Mil											
		As Received			After 250 Deg F for Two Hours			After 350 Deg F for Two Hours			After 450 Deg F for Two Hours		
		Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
Yellow Insulating Varnish													
Cotton	0.0093	842	915	1,038	911	982	1,046	928	982	1,019	964	1,065	1,121
Glass	0.0100	807	1,018	1,067	1,105	1,145	1,200	1,277	1,289	1,310	1,411	1,487	1,586
Black Insulating Varnish													
Cotton	0.0105	1,148	1,296	1,386	1,332	1,370	1,444	1,092	1,220	1,335	1,052	1,105	1,132
Glass	0.0095	1,243	1,312	1,368	1,220	1,362	1,538	1,187	1,372	1,680	1,195	1,400	1,518
After Creasing*													
Yellow cotton	0.0095	317	590	844	272	422	523	169	403	675	201	440	638
Yellow glass	0.0097	524	563	606	481	532	642	548	677	767	541	665	917
Black cotton	0.101	139	519	872	152	538	721	105	122	141	99	121	129
Black glass	0.0096	733	876	984	713	933	1,242	170	462	940	156	398	1,015

NOTE: All samples in table V were taken from standard rolls of cloth varnished by a manufacturer of varnished cotton cambric, the same respective varnishes being used on both the cotton and the glass. Nominal thickness of cloth was 0.010 inch but actual average thickness determined with a one-fourth-inch-diameter micrometer are shown for the cloth as received. Each value of dielectric strength is maximum, average, or minimum of ten readings of breakdown voltage divided by the average of ten readings of thickness determined separately for each sample. All tests were made by the short-time method at room conditions of approximately 80 deg Fahrenheit and 65 per cent relative humidity, using standard two-inch-diameter electrodes. Voltage was increased at the rate of 500 volts per second to breakdown.

* Samples were creased by bending double both ways and creasing between thumb and index finger as in creasing paper for tearing. Electrodes were placed directly over the creases.

Table VI. Dielectric Strength of Fiber-Glass Cloths Impregnated With Various Insulating Varnishes After Heating at 350 Degrees Fahrenheit for 140 Hours

Sample number		1	2	3	4	5	6
Impregnant		Clear air-drying varnish	Clear baking varnish	Clear baking varnish	Alkyd resin varnish	Yellow cambric insulating varnish	Black cambric insulating varnish
Average thickness (inch)		0.0067	0.0107	0.0075	0.0081	0.0076	0.0074
Dielectric strength (volts per mil)	Maximum	1,460	1,498	1,815	1,767	1,559	1,438
	Average	1,170	1,111	1,590	1,561	1,383	1,230
	Minimum	893	608	1,194	1,437	1,190	1,008

NOTE: Sample numbers 1, 2, 3, and 4 prepared by hand dipping thoroughly clean 0.004-inch-thick continuous-fiber glass cloth in comparatively thin solutions of varnishes, each one receiving three coats. Samples 5 and 6 were taken from the same rolls of commercially varnished cloth as the samples of table V.

there was one inch of slack when the pulley clamp was at the point of maximum distance from the stationary clamp. The pulley was rotated at a speed of 300 rpm creating a whipping motion causing a constant flexing of the fibers within the tape. Readings were taken of the time required to wear out each sample. Test values are shown only to the nearest hundred flexes.

Dielectric Strength

The dielectric strength of unimpregnated fiber-glass insulation as it comes from the loom is about the same as that of equivalent cotton textiles, both being determined largely by atmospheric conditions, fiber surface contamination, etc. If the effect of the surface contamination be minimized by thorough washing and drying, the dielectric strength of the glass increases approximately 3 per cent, but that of the cotton decreases about 6 per cent and asbestos about 12 per cent, due to the absorption of moisture and the attendant swelling.

The results of tests on three types of unimpregnated tape, asbestos, cotton, and glass, both "from-the-loom" and washed, are shown in table IV.

Table V shows a direct comparison between the dielectric strengths of commercially varnished cotton cambric and varnished fiber-glass cloth after various short-time heat treatments, the varnishes used being the same for both cotton and glass cloth.

It will be noted that in the case of the black varnish, there is little difference between the cotton and the fiber-glass averages after subjection to temperatures up to 250 degrees Fahrenheit. But after 350 degrees Fahrenheit and 400 degrees Fahrenheit for two hours, the averages for the glass are 11 per cent and 27 per cent higher than those for cotton.

The differences in the case of the yellow varnish (which, of course, has greater heat resistance than black varnish) are more pronounced, varying from 11 per cent with no heat treatment to 40 per cent after heating at 450 degrees Fahrenheit for two hours.

Perhaps the most plausible explanation for these results is that the heat treatment was sufficient to cause an appreciable amount of carbonization of the cotton fibers and yet not severe enough adversely to affect the dielectric strength of the varnish or the glass fibers. In fact the values in table V again demonstrate the already accepted fact that heat treatment of this nature definitely improves the dielectric strength of most insulating varnishes.

Table VI is included here to show some of the results obtained in efforts to determine what dielectric strengths could be expected of fiber-glass cloths impregnated with heat resistant varnishes after subjection to sustained high temperatures. Samples numbers 1, 2, 3, and 4 were prepared by hand-dipping 0.004-inch-thick continuous-fiber glass cloth (previously washed) into thin solutions of the varnishes, each being given three coats. Samples number 5 and 6 were varnished commercially (from same rolls as samples in table V).

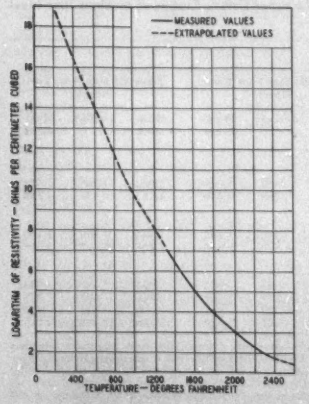

Figure 2. Volume resistivity of alkali-free glass

In hand application ordinary varnished tapes are often stretched sufficiently to exceed the elastic limit of the varnish thereby impairing their insulating value. As glass fibers do not stretch, the varnish on glass tapes is not impaired in this manner.

It is not intended that these values be considered as directly comparative for the reasons that the thickness of the finished samples varies considerably and that two of the samples were varnished on standard varnishing towers and the rest hand-dipped. It is significant, however, that for five of the six samples the values of minimum dielectric strength are well above the accepted specifications for varnished cotton cambric and the minimum of one sample is over 1,400 volts per mil.

All samples were heated in a thermostatically controlled electric resistance

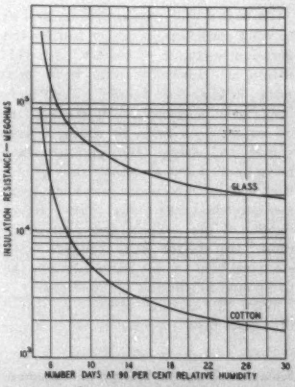

Figure 3. Samples of 0.010 inch by 1 inch by 1 inch black varnished cloth after heating at 350 degrees Fahrenheit for two hours

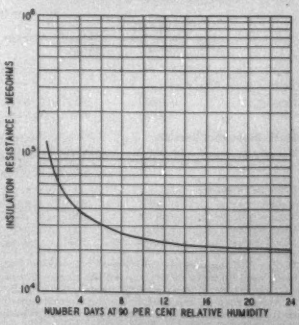

Figure 4. Glass tape 0.010 inch by 1 inch coated with water-soluble bakelite

Figure 5 (above). Standard roll of continuous-fiber tape 0.003 inch by ¾ inch

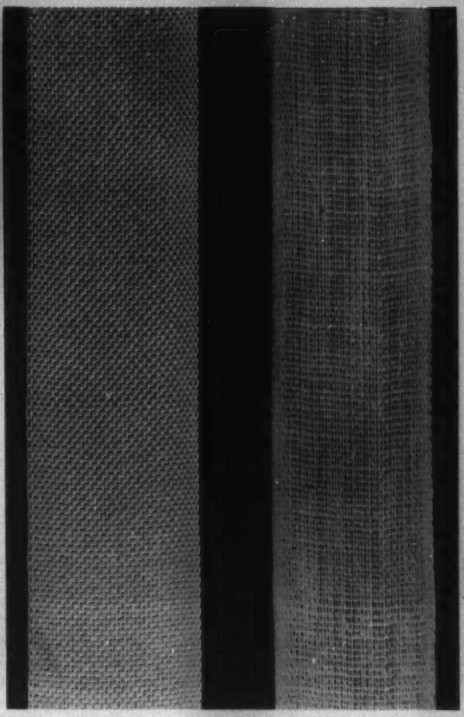

Figure 6 (left). 0.003 inch by ¾ inch standard continuous glass tape; right—0.007 inch by ¾ inch standard cotton tape

oven at 350 degrees Fahrenheit for 140 hours and tested for dielectric strength at room condition of approximately 80 degrees Fahrenheit and 65 per cent relative humidity within two hours after being removed from the oven.

It is well known that varnished textiles tend to become brittle at high temperatures and are therefore subject to cracking and subsequent dielectric failure. Glass textiles are no exception to this rule, but table V shows that the effect of the brittleness of the impregnant is not so pronounced on glass fibers as on the weaker and less-heat-resistant cotton textiles.

One test often used as a criterion for flexibility of a piece of varnished cloth is to bend it around a one-eighth-inch-diameter rod. If no cracks are observed in the varnish, the cloth is considered to be sufficiently flexible. Table V shows the results of a more severe test for the weakening or cracking of the varnish on cotton and fiber-glass cloths after various heat treatments. After the heat treatment, the samples were creased by bending double both ways and creasing between thumb and index finger as creasing paper for tearing. The two-inch-diameter electrode was placed directly over the crease in making dielectric strength tests.

It will be noted by comparing values in the third column in table V that creasing causes the "as received" yellow cotton to lose 62 per cent of its original minimum value, yellow fiber glass loses 41 per cent, black cotton 88 per cent, black glass 41 per cent. After 350 degrees Fahrenheit for two hours the percentage loss for yellow cotton is 80 per cent as against 39 per cent for the yellow glass cloth.

Insulation Resistance

A. Volume Resistance

The volume resistivity of the alkali-free glass used for electrical insulation is much greater than that of the glasses listed in the International Critical Tables. This is attributed to the absence of soda and potash which have been found by Littleton and Morey[1] to decrease the volume resistivity of solid glass considerably. Figure 2 shows the volume resistivity of electrical-insulation glass at different temperatures. Six determinations between 1,360 degrees Fahrenheit and 2,460 degrees Fahrenheit were made in essentially the same manner as was used by Kohlenrausch[2] in determining the conductivity of salt solutions. The electrodes used were made of platinum and were calibrated with a number of standard solutions having approximately the same range of resistivity as molten glass. A 1,000-cycle source of power was used and resistance measurements made by means of a General Radio type 650-A impedance bridge.

B. Surface Resistance

Because of the high ratio of exposed surface area to the total weight of fiber glass (about 1,500 square feet per pound) measured values of insulation resistance at normal temperatures may be considered as purely surface resistance without appreciable error. This surface resistance is affected not only by the glass constituents, but to a very marked degree by the relative humidity of the atmosphere. This is illustrated in table VII which shows the insulation resistance

Table VII. Insulation Resistance in Megohms of Standard Unimpregnated Tapes One Inch Square After 72 Hours at 100 Degrees Fahrenheit and 90 Per Cent and 75 Per Cent Relative Humidity

	"From the Loom"		Washed	
	90 Per Cent Relative Humidity	75 Per Cent Relative Humidity	90 Per Cent Relative Humidity	75 Per Cent Relative Humidity
0.015 by 1 inch asbestos	0.57	1.08	1.5	5.5
0.011 by 1 inch cotton	1.03	35	30.5	380
0.015 by 1 inch glass	12.4	200	1,400	30,100

Figure 7. View in twisting mill showing the fabrication of continuous-fiber glass yarns

across one-inch-square samples of standard unimpregnated tapes both from the loom and washed (boiled 15 minutes in 0.5 per cent solution of soap in distilled water), after being held at 100 degrees Fahrenheit and the indicated relative humidities for 72 hours.

Figure 3 shows the variation in insulation resistance of one-inch-square samples of black varnished cotton and glass cloth over a period of 30 days at 100 degrees Fahrenheit and 90 per cent relative humidity.

When fiber-glass tape is coated (not impregnated) with a solution of a water-soluble bakelite and then dried, the insulation resistance becomes higher than that of the untreated tape. Figure 4 shows the variation in insulation resistance at 90 per cent relative humidity of a sample prepared in this manner. The solution of bakelite was $12^1/_2$ per cent solids by weight and the sample was dried for 90 minutes at 250 degrees Fahrenheit.

All insulation resistance determinations were made with a Leeds and Northrup insulation-resistance test set of the guard-circuit type consisting of high-sensitivity galvanometer, Aryton shunt, and lamp and scale device. The electrodes were brass clamps supported in a bakelite board on two-inch centers one being guarded by a brass ring. The bakelite board served as the cover for a $4^1/_2$-inch-diameter glass jar, in the bottom of which was a saturated solution of the proper salt for the desired humidity. (KNO_3 was used for 90 per cent relative humidity and NaCl for 75 per cent relative humidity at 100 degrees Fahrenheit.) The guard circuit was complete from electrode to galvanometer. Source of current was five 45-volt radio *B* batteries in series. Readings were taken one minute after the specimen circuit was closed.

The results obtained by R. E. Ferris and G. L. Moses of the Westinghouse Electric and Manufacturing Company on the insulation resistance of a cotton-insulated coil and an asbestos insulated coil at 99 per cent relative humidity show essentially the same trend over a period of 14 days as is seen in figure 3 although the asbestos failed to ground on the 13th day.

Hygroscopicity

One of the most difficult problems to solve in connection with electrical insulation is that of failure due to the absorption of moisture. In some cases this is the primary concern of design and maintenance engineers. Glass insulation, being nonhygroscopic, is proving valuable under extreme conditions of high relative humidity coupled with intermittent high overload temperatures. Notable examples have come from the bituminous coal fields of western Pennsylvania. One company, which operates a large number of mining locomotives, reports that the average life of motor windings operating under the worst conditions has been lengthened considerably by the use of fiber-glass-insulated coils.

Reference to table IV will show that after washing and thorough drying, the average thickness of cotton and asbestos tapes had increased. This does not occur in glass tapes.

Glass insulation is available in the same forms and sizes as are other fabrics, the following being stocked:

Tape. Continuous fiber 0.005 inch by $^1/_4$ inch to 0.015 inch by $1^1/_2$ inches; staple fiber 0.010 inch by $^1/_4$ inch to 0.025 inch by $1^1/_2$ inches.

Braided Sleeving. Made from continuous-fiber yarns in standard inside diameters of $^1/_{16}$ inch, $^1/_8$ inch, $2^1/_4$ inches with wall thickness of 0.015 inch.

Varnished Cloth and Tape. Black and yellow varnished cloth and tape are available in the same widths and thicknesses as varnished cotton cambric.

Glass Insulated Wire. All sizes of round and square wire are being covered successfully with glass yarn, different thicknesses being used to obtain the same over-all diameters as standard wire insulated with asbestos, cotton, paper, and silk.

Combination Mica and Glass. A number of mica and glass combinations are being used for transformer coil, and armature coil, and slot insulation. This combination is a class-*C* insulation except for a small amount of organic binder.

Summary

In summing up the characteristics of fiber glass those which make it valuable for electrical insulation are:

1. Noninflammable and highly heat resistant. The operable temperature is limited only by the impregnant used, and there is a very definite temperature range between the operable temperature of organic fabrics and that of heat-resistant impregnants where glass is unique.
2. Exceptionally high tensile strength.
3. Nonhygroscopic.
4. Resists attack by moisture, acids, oils, and corrosive vapors.
5. Good thermal conductivity.
6. Excellent dielectric strength when impregnated.
7. High insulation resistance.

References

1. Electrical Properties of Glass, Littleton and Morey, John Wiley & Sons.
2. Conductivity of Solutions, Cecil W. Davies.

Discussion

L. E. Fogg and **R. B. Power** (Kennecott Wire and Cable Company, Phillipsdale, R. I.): Mr. Atkinson has outlined the properties of fiber glass which promise to make it an important factor in the field of electrical insulation. These properties are such that frequently fiber glass may be used advantageously in place of other insulations and it may provide a satisfactory solution for a number of difficult insulation problems. There are, however, a few comments that should be made with regard to the use of this material.

There is one point in connection with the mechanical strength of the material which would bear some clarification. The results of the flexing endurance tests as reported in table III show that a certain amount of heat treatment apparently toughens the insulation, and might make such treatment a desirable part of the preparation of the material. The cause for this improvement is not readily apparent, and should have some explanation by the author.

In table IV giving dielectric strength comparisons, Mr. Atkinson has indicated slight improvements of the glass, and slight loss for the other insulations through washing. For thin insulations there is always an increase in the dielectric strength as the thickness of the material is decreased. It seems probable that this factor is more responsible for the slight increases and decreases noted above, than any other change in the insulations. The cotton and asbestos fabrics, showing increases in thickness with washing, show a corresponding decrease in dielectric strength, while the glass, with a decrease in thickness shows an improved dielectric strength.

The lubricating oil applied to the fiber during manufacture may have some slight effect on the dielectric strength of the glass tape. However, this oil may be very detrimental if thermal and electrical conditions of insulation use are such as to make dielectric loss an important factor.

It is worth pointing out that the dielectric strength of asbestos may vary greatly from the values shown in the same table, depending on the method of preparing the asbestos tape. Some comparative dielectric-strength measurements were made recently at our laboratory on fiber glass and asbestos tape in which the asbestos had been fabricated on a cotton backing. Although the fiber glass gave results almost identical with those of Mr. Atkinson, this asbestos tape showed about 60 per cent higher dielectric strength than did the samples he reported.

It is unfortunate that in most applications of fiber glass as insulation it is necessary to use some bonding, saturating, or coating material in conjunction with the glass. Some tests which we have made recently show that if fiber glass alone could be used it would retain some insulating properties at temperatures approaching its softening point. Such temperatures cannot be attained in practical applications, however, and in most cases the maximum operating temperatures for fiber-glass-insulated equipment will be limited to a moderate value by associated insulating materials. These facts should be kept in mind when considering fiber-glass insulation for high-temperature operation.

Unquestionably, glass as a fibrous insulating material will eventually find its proper place among other similar materials. The information presented by Mr. Atkinson should indicate some places where its use would be definitely practicable.

R. W. Wieseman (General Electric Company, Schenectady, N. Y.): For rotating-machine windings a large variety of class *A* organic insulating materials are available. These materials are inexpensive, easy to apply, and they have been used successfully for many years. As the machine voltage, speed, and size increased inorganic materials were introduced to increase the life of the windings by resisting the action of mechanical stresses, corona, and elevated temperatures.

Unfortunately only two inorganic materials were suitable for rotating-machine windings up to the present time, namely, asbestos and mica in built-up form. Mica is an excellent high-voltage high-temperature moisture-resisting insulator if properly filled and bonded. It is limited mechanically, however, by the characteristics of its bonding medium. Some asbestos textiles contain as much as 20 per cent cotton. It is well known that asbestos absorbs moisture readily and it contains natural ferrous particles and conducting salts which must be removed if it is to be used in the region of high-voltage stresses. Asbestos, therefore, is usually confined to low voltages where mechanical strength is required at elevated temperatures and as an armor for high-voltage mica insulation. It is apparent that present inorganic materials, although satisfactory, are not ideal for rotating-machine insulation.

The introduction of glass-fiber insulation is welcomed by those interested in rotating machines. When properly filled with a suitable varnish or compound, glass fiber is a good class *B* insulating material. Up to the present time glass fiber alone is not a competitor to mica for high-voltage windings. Glass fiber, however, should be beneficial in many respects. First, it can replace cotton which is used for structural purposes in class *B* insulation, and thereby produce better mechanical and thermal properties. Second, it can replace asbestos with an improvement in uniformity, mechanical strength, and voltage strength. Third, it can partially replace mica on low- and medium-voltage coils with an improvement in mechanical strength. It also can be used as an armor or outside covering for high-voltage mica-insulated coils.

D-c and a-c machines have been built with glass-insulated wire in both the armature and field windings. Coils of many kinds have been insulated with glass tape and mica in several combinations. The end connections of armature windings have been insulated with treated glass tape and combinations of glass and mica tape. A 1,500-kw 600-volt d-c machine was insulated entirely with mica and glass. None of its six windings contains cotton or asbestos in any form. Insofar as machine temperatures are concerned the thermal limitation of the windings of this machine is governed only by the insulating varnish and filling compounds used in building the insulation structure.

Glass fiber in various forms can be used to advantage in rotating-machine insulation. The extent to which it will replace present materials will depend somewhat on technical and economic conditions because its feasibility has been established.

E. F. Dissmeyer (The Commonwealth and Southern Corporation, Jackson, Mich.): Mr. Atkinson's paper provides a very complete comparison of the characteristics of cotton and glass when used as insulating materials. In the future, glass will undoubtedly provide an answer to many of our insulation application problems.

A number of other characteristics of glass insulation would, of course, be of interest. Certain of these are:

1. How does the dielectric strength of glass under impulse conditions compare with that of other insulating materials?

2. In transformer applications, a majority of the dielectric strength between turns is provided by the oil-saturated paper covering on the conductors. Would a glass reinforcement over the paper provide better dielectric strength?

3. One of the problems which confronts the manufacturer is that of getting varnish into the interior of coils. With cotton insulations, the varnish can be "wicked" in only a short distance. How do the "wicking" properties of glass compare with those of cotton?

E. L. Lotz (New Jersey Wood Finishing Company, Woodbridge, N. J.): The information on fiber glass presented by Mr. Atkinson is extremely valuable and timely in view of the newness of the product and of the widespread interest in this type of insulation and of the possibility of the increased temperature ratings of electrical equipment and allied insulation.

With the tremendous advances made in the manufacture of insulating varnishes and impregnating compounds in the last few years, it has become more and more apparent that the limiting factor in the operation of insulation at high temperatures is not the varnish or impregnating compound, but the carrier on which they are used. Cotton when impregnated or coated and subjected to high temperatures (125 degrees centigrade) fails only in a mechanical sense, that is, it fails in so far as tensile and tearing strength are concerned but does not fail electrically as the dielectric strength of the varnish or compound will, if anything, be higher after the heat treatment. The use of fiber glass as the carrier should insure both good electrical and mechanical properties even after exposure to high temperatures for long periods of time.

The dielectric strength of cotton and glass impregnated with the same varnish is substantially the same as is also the case for the two in the unvarnished state. This means that the dielectric strength is determined almost entirely by the type of varnish used, as is clearly shown in table VI of the paper.

The curves in figure 3 are very interesting and would tend to show that varnished glass cloth is considerably better than varnished cotton cloth under conditions of high humidity. I have tested both glass and cotton for resistance to moisture and have found that varnished cotton compares very favorably with varnished glass in respect to power factor and dielectric strength. The experiment consisted of vacuum-drying samples of black varnished cotton and fiber glass at

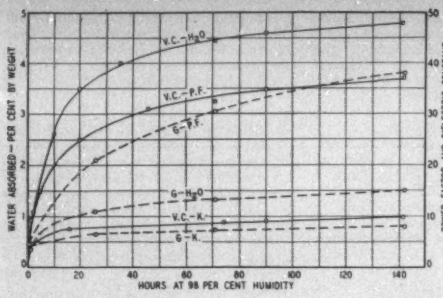

Figure 1. Water absorption of varnished glass and cotton

105 degrees centigrade for six hours under a vacuum of 0.1 millimeter and then exposing the samples to 98 per cent relative humidity and determining the amount of water absorbed, the power factor, and dielectric constant. The result of this experiment is shown in figure 1 of this discussion. The curves are plotted against hours of exposure and show that even though the varnished glass absorbed much less water, the resultant power factor was just as high as the varnished cotton. The curve designated *V.C.-P.F.* means the power factor of the varnished cotton, whereas, *G-P.F.* is the similar curve for varnished glass. In both cases, there was an initial rapid increase in water absorbed, power factor, and dielectric constant in the first ten hours.

In order to compare the dielectric strength after exposure to moisture, samples which had been vacuum dried as above were immersed in water at 24 degrees centigrade for 24 and 42 hours and the amount of water absorbed and decrease in dielectric strength measured. The dielectric strength was measured using one-fourth inch electrodes and the short time ASTM method of test. The results are shown in table I of this discussion. After 24 hours, the varnished glass had absorbed 0.77 per cent water by weight and had a reduction in dielectric strength of 46.2. Varnished cotton absorbed 3.2 per cent water by weight, but the reduction in dielectric strength was only 30.85. After 42 hours the glass had absorbed 1.1 per cent water by weight with a reduction in dielectric strength of 59.2 per cent. The varnished cotton absorbed 4.35 per cent water by weight and had a decrease in dielectric strength of 48.5 per cent.

Table I. Water Absorption-Dielectric Strength

Exposure	Water Absorbed (Per Cent by Weight)	Per Cent Reduction in Dielectric Strength
Black Fiber Glass		
24 hours in water at 24 degrees centigrade	0.77	46.2
42 hours in water at 24 degrees centigrade	1.1	59.2
Black Cotton Tape		
24 hours in water at 24 degrees centigrade	3.2	30.85
42 hours in water at 24 degrees centigrade	4.35	48.5

In the above experiments, the same varnish was used on both the cotton and glass and it is reasonable to assume that in each case the varnish itself would be affected to the same degree so that the difference in the performance of the two must be directly dependent on the carrier. Since glass is nonhygroscopic the mechanism of the water absorption is probably of the nature of a surface layer on the glass fibers. In the case of cotton most of the water is taken up by a wick action and since the carrier itself does not contribute anything to the dielectric strength, the presence of the large amount of water in the cotton does not show up in the dielectric-strength measurements.

Lloyd E. Miller (Reliance Electric and Engineering Company, Cleveland, Ohio): Mr. Atkinson's paper is so complete as to detail, that it leaves practically nothing to the imagination and very little concerning the physical characteristics given in the paper, to discuss.

There is, however, a feature that might very well be discussed regarding the commercial usage of this material. The high temperature to which fiber glass can be subjected has been stressed in this paper and in previous papers and talks. It might be said to have been overstressed. It has been stressed so much that it has been ill advisedly seized on by many as proof that with this material the industry is now ready to double the temperature at which electrical machinery can be operated.

The fact that impregnants must be used in conjunction with fibrous insulation, and the fact that all satisfactory impregnants to date are entirely, or in part, of organic material, and are, therefore, the limiting factor in such combination, seems to have been neglected. It is noted that Mr. Atkinson mentions this in his paper, but it seems that it should be more strongly emphasized than in the past. This fact should serve as a spur to the varnish manufacturers.

It does seem that the electrical industry might profitably consider higher temperatures than are now sanctioned, but extreme changes due to new materials should be approached with caution.

It should be borne in mind that the ability of fibrous insulation to withstand high temperatures is not of itself sufficient to justify such changes. Fire hazard must be considered, as must also strains and movements set up by expansion and contraction.

There is no doubt that the new fibrous glass has given the electrical industry a substantially improved insulating material. It can be accepted as a fact that its heat-resisting properties are considerably above those which can be used by the industry at the present time. It would, therefore, seem that efforts of the manufacturers should be along the line of making the product easier to use and apply.

Graham Lee Moses (nonmember; Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): Mr. Atkinson and his colleagues in the Owens-Corning Fiberglas Corporation have undoubtedly made a very significant contribution to the insulation art. Insulation engineers have long felt that existing class *B* insulating materials had definite limitations and it is hoped that this new material will overcome these defects.

Our experience with fiber glass parallels Mr. Atkinson's on some phases of tests on the fundamental material. However, our experience has largely been in connection with actual commercial machines. We have found that its success depends upon the correct application. It has proved satisfactory on equipment where weight and space requirements necessitate high-temperature operation and the insulation is exposed to high humidity conditions. Our experience in the application of glass insulation to transportation apparatus is detailed in an article by Mr. Ferris and myself which appeared in the December 1938 issue of ELECTRICAL ENGINEERING.

Our practical and design experience with glass insulation on commercial apparatus covers a period of nearly two years involving over 50 types of motors and generators and several hundred units. It has also been used on many types of control.

Fiber-glass insulation has its share of desirable characteristics and naturally has its limitations. It should not be substituted wholesale for any existing insulating medium but should be applied with care and consideration only where it is required and its use is economically justified. Applications should be avoided which bring out or emphasize its limitations or weaknesses.

Glass insulation by virtue of its excellent tensile strength under high temperature conditions lends itself to being used for binding class *B* coils and holding other forms of insulation in place. It makes an excellent finishing tape producing the desired strength with long life at high temperatures and a fine glossy finish when properly treated. The excellent tensile strength permits the use of thinner class *B* tapes thereby obtaining improved space factor.

Because it is a woven material its inherent (untreated) dielectric strength is only comparable to that of similar conventional materials. When treated it takes on the characteristics of the impregnant film as do other woven materials. In our opinion it should not be used for the main ground insulation on high-temperature class *B* apparatus. This material is of course not to be considered to replace mica for ground insulation.

One of the present limitations of glass insulation is its relatively low resistance to abrasion when the fibers are not lubricated or supported by impregnation. In tape

form the fibers are lubricated by an oil film applied during manufacture. In the apparatus this must be supplemented by varnish or other impregnant. When this lubricant or impregnant is eliminated or its qualities destroyed, vibration is apt to cause abrasive destruction. This very definite limitation must be faced by engineers applying this material.

Another limitation is the relatively low shear strength of the glass fibers. This is an exhibition of the brittleness which has long been associated with glass. To avoid this, apparatus should be designed to prevent exposing glass insulation to sharp corners or edges.

The smooth, silky appearance produces another handicap as it permits the warp to slip on the weft, unless a very close weave is used. This tendency can be minimized by pretreating the tape in varnish and only partially curing before applying the tape.

The next logical step in the development of high-temperature insulation is the production of a high-temperature impregnant properly to lubricate or support glass insulation and give it high dielectric strength at elevated temperatures. In most of the previous points discussed the impregnant is an important factor. The importance of this cannot be overemphasized and the development of fiber-glass insulation has in effect "passed the ball" to the impregnant manufacturers.

In our search for improved insulation to operate at elevated temperatures it must be remembered that as insulation improves it ceases to become the determining factor. Already there are important considerations requiring the operation of some classes of machinery at temperatures below that now permissible for insulation.

One interesting and spectacular experiment which we made, was to operate glass-insulated magnet coils at temperatures around 575 degrees centigrade (1,067 degrees fahrenheit). Some of these operated several hours without failure even though the impregnant was completely destroyed. Naturally, life at this temperature is limited and there was no intent to operate apparatus at such temperatures but it was merely done to demonstrate the reliability under extreme conditions due to failure elsewhere in the control equipment.

Briefly glass insulation is an important addition to our family of insulating materials. It is not a panacea nor a cure-all. In our opinion it should be applied judiciously with full appreciation of the limitations as well as the important advantages. Westinghouse engineers, in the early stages of this development, recognized the possibilities of fibrous glass insulation and recommended the use of the continuous-filament type.

T. R. Walters (General Electric Company, Pittsfield, Mass.): The data presented in this paper add considerable to our understanding of this new and very interesting insulating material. The point is well brought out that in the field of varnished fabrics the fabric base is the weaker part of the structure and consequently, replacing the organic with an inorganic fabric has a very beneficial effect on the heat resistance of this class of material.

There are several other points which I would like to bring up. One is that while the data show definitely that fiber glass will successfully withstand a much higher temperature than either cotton or asbestos before losing its tensile strength, these tests were all on a short-time basis. It would be interesting to know just how high a temperature these new fibers will stand successfully for very long periods of time. Also, as a matter of record, were the tensile tests reported taken at the temperatures shown on figure 1, or were they taken at room temperature after aging at the indicated temperatures?

In the section concerning dielectric strength, it is stated that "The dielectric strength of unimpregnated fiber-glass insulation as it comes from the loom is about the same as that of equivalent cotton textiles." This being so, I would be interested in the author's theory as to why fiber-glass insulation produces higher dielectric strengths than cotton when the same varnishes are used. A possible explanation is given for the results obtained after heat treatment but not for the higher results obtained on the samples before aging.

In another part of this same section, a statement is made that "In hand application ordinary varnished tapes are often stretched sufficiently to exceed the elastic limit of the varnish, thereby impairing their insulating value," followed by the statement that since glass fibers do not stretch, the varnish on glass tapes is not impaired. Varnished cotton cloth can also be made which will not stretch. Quite often, however, due to the nature of the surface to which the tape is being applied, it is necessary to use tape which will stretch. The decrease in dielectric strength in this instance, is small for the amount of stretch usually required for satisfactory taping.

Wm. A. Del Mar (Habirshaw Cable and Wire Corporation, Yonkers, N. Y.): Fiber glass, from the point of view of the cable designer, is not so much an insulating material as a vehicle or filling for such insulating materials as wax, varnish, or lacquer. In this respect it may be regarded as a competitor of cotton, dry paper, and asbestos. The characteristics of fiber-glass insulation, such as dielectric strength, power factor, and ability to resist heat, cold, or moisture, are essentially those of the associated wax, varnish, or lacquer. Fiber glass gives body and strength to these materials, enabling them to be applied in thicker layers. Its advantages over other fibers are that it does not impair the useful characteristics of the wax, varnish, or lacquer with which it is associated. From this it would appear that the title of this paper is misleading as fiber glass is merely an inorganic vehicle for air or organic insulation.

Fiber glass has a definite value for certain classes of wire such as magnet wire, fixture wire, and small motor leads but, so far, it has not made much headway for the larger types of cables.

Fiber glass is a valuable braid material as it does not decay, burn, or become waterlogged. Here, again, its characteristics are limited by the organic filler which must be used. It is more likely that its application to power cables for some time to come will be along this line rather than for the insulation itself. The present high cost of the fiber glass, as compared with other braid materials, limits its use in large cables to services where other available materials show abnormally rapid deterioration.

Varnished glass cloth insulation, as now made, does not stand heat (96 hours at 125 degrees centigrade) as well as heat-resisting varnished cambric made with the same varnish. It becomes more brittle than the cotton base material. It is to be hoped that this material will be developed to the degree of heat resistance that seems to be inherent in the component materials.

K. N. Mathes (General Electric Company, Schenectady, N. Y.): Mr. Atkinson's paper constitutes an excellent survey of the properties of glass fiber insulation. From the standpoint of the manufacturer of electric apparatus the properties and service life in built-up form are of primary importance. Service trials and laboratory tests have established that the electrical and particularly the physical properties of glass fiber insulation depend largely upon the nature and thoroughness of the compound or varnish treatment.

Untreated glass fibers are extremely sensitive to nicking, and unless protected can even cut and destroy each other under conditions of abrasion and vibration. For this reason a film of oil or sizing is applied to the fibers to protect them in the textile operation and allow their use as yarn or fabric. The sizing used at present is somewhat corrosive to copper, hygroscopic, and, in addition, is not truly compatible with most insulating varnishes. Because of the nature of the sizing and the high density in the case of the continuous-filament yarn, it is difficult to secure complete varnish or compound penetration. Although glass is not hygroscopic in the sense that the solid fibers can absorb water, moisture can be picked up in the following ways:

1. As an adsorbed film upon the glass surface.
2. By adsorption in the sizing.
3. By capillarity between fibers or threads.
4. By capillarity between fibers and surrounding varnish which may not satisfactorily wet the fiber.

As a result the moisture resistance of glass fiber as measured by the electrical properties in many cases is only comparable to cotton.

When used as major insulation, the glass fabric serves merely as a matrix to carry the insulating varnish. The extent of the deterioration of the varnish over long periods of time is extremely important. The most characteristic effect is the slow embrittlement and tendency toward cracking which may seriously impair the dielectric strength. In contrast, the overlapping flakes of pasted mica depend upon varnish only as a binder. In addition, since all organic varnishes deteriorate under the action of corona, the varnished glass fabric cannot be considered as a substitute for mica in high-voltage applications.

This discussion emphasizes limitations and precautions which are important to recognize since glass fiber is assuming so rapidly an important place in the field of electrical insulation. Glass insulation has found use in many types of electric apparatus, and will find increased use with further development, and as service data more firmly establish the advantageous proper-

ties. In comparison with other types of insulation, in many cases economic consideration may be the deciding factor for use.

H. C. Louis (Consolidated Gas, Electric Light and Power Company of Baltimore, Md.): The data in the paper giving the results of the elaborate tests on fiber-glass insulation show this material to have some very desirable and superior characteristics and to open up some very attractive possibilities. The development of this insulating material marks a definite step forward in the progress of insulation development.

Numerous mechanical tests were made as described in the paper, but we wish to stress the importance of giving full consideration to the effect of fatigue effects from vibration. The possibility of deterioration or even pulverization of such material due to this effect in extended service should not be minimized. Operating experience shows numerous troubles in materials to be traceable to vibration fatigue, and possibilities of anticipating and preventing this call for the very best efforts and attention in investigations of the material under consideration.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): The utilities are, of course, gratified to learn again that the manufacturers are investigating the new kinds of insulation as they are brought forth. Obviously, when these insulations are suitably developed by themselves or as incorporated in apparatus, many utilities will be glad to use them when they become attractive commercially as well as technically.

Referring to the newer insulation, that is, glass, it would be of interest to learn what developments have been made with other types of binders than the varnish and bakelite mentioned by the author. This question, of course, is raised in connection with frequent or continuous operation of glass insulation in apparatus at such temperatures as 150 or 175 degrees centigrade.

F. W. Atkinson: L. E. Fogg, R. B. Power, and Lloyd E. Miller refer to the fact that the operable temperatures for glass insulation in most applications must be limited by the impregnant used. Mr. Miller advises caution in design and rating changes in the direction of higher temperature operation, and Herman Halperin raises the question as to impregnants which may be capable of withstanding temperatures such as 150 degrees centigrade or 175 degrees centigrade.

The author fully realizes the necessity for caution in raising the temperature ratings of electrical apparatus in general and that many other considerations make it impossible to operate at temperatures even approaching those which glass will stand. However, as E. L. Lotz and Graham Lee Moses have pointed out in their discussion, as far as the insulation is concerned, the limiting factor with impregnated glass is the impregnant, whereas with class *A* insulations, it is the fabric. Our tests of numerous varnishes on glass and cotton fabrics definitely show that the better heat-resistant varnishes will stand temperatures considerably higher than those which cause cotton to lose practically all of its mechanical strength. Our experience with the relative heat resistance of varnished glass cloth and varnished cotton cambric does not parallel that of Wm. A. Del Mar. Of three different samples of yellow varnished cotton cambric held at 125 degrees centigrade for 168 hours, only one could be bent 180 degrees around a one-eighth-inch-diameter mandrel without cracking. All of the six samples of yellow varnished glass cloth (each varnished by a different company) withstood this test. A few of the better commercial varnishes (applied to glass cloth) have been found to pass this test after a week at 175 degrees centigrade. One experimental impregnant, partly organic, retained remarkable flexibility after 120 hours at 200 degrees centigrade and its minimum dielectric strength was over 1,500 volts per mil (short-time method, one-fourth-inch electrodes, material 0.010 inch thick). It seems reasonable, then, to assume that:

1. The temperature limits of class *A* insulations are determined by the fabric and not by the impregnant.

2. With a fabric that will stand it, varnishes are available which can be used where hot spot temperatures are 150 degrees centigrade or higher.

3. The final word has not been written about heat resistance in impregnants as varnish manufacturers and individuals are making great strides in the improvement of this quality. It is believed that the introduction of glass fabrics into the insulation field has provided further inducement to effort on this particular research problem.

K. N. Mathes and Graham Lee Moses have mentioned the low resistance of untreated glass fabrics to abrasion and shear on sharp edges. This probably is the weakest property of the untreated glass at the present time, although that is not true of treated fabric and it does not seem to be of primary importance. Laboratory tests along this line are not very conclusive so it seems pertinent to refer to the experience encountered by manufacturers in the actual application of "Fiberglas" insulating materials during the three years since their introduction. Few have reported any lasting difficulty due to abrasion and shear and some have indicated as much as 15 per cent saving in labor in the winding of coils. This would hardly be possible if much difficulty were encountered due to nicking and shearing during fabrication. It should be pointed out further that continuous research is definitely minimizing this weakness.

Mr. Mathes mentions the important point of thoroughness of impregnation of treated Fiberglas insulation. This problem, of course, is as applicable to glass as to the other textile insulating materials but no particular difficulty has been found in our laboratory in obtaining thorough impregnation of glass cloth, and the impregnation of wound coils is being carried on by numerous manufacturers with facility and efficiency at least as great as with cotton and asbestos. We have found, however, that some types of varnish wet glass fibers much better than others and this seems to be the high hurdle in accomplishing thorough impregnation of Fiberglas. Heat treatment definitely improves impregnation by strengthening the bond between the varnish and the fibers. We believe this to be, in part, the answer also to the question of Messrs. Fogg and Power regarding the increase in flexing strength of varnished cloth after heat treatment. Another explanation is that the polymerization of thermosetting varnishes adds considerably to their toughness.

T. R. Walters raises the question of variation in tensile strength of Fiberglas with time of exposure to high temperatures. Our experience indicates that there is very little change in the tensile strength of electrical glass (alkali-free) after the first 24 hours.

Cloths made of this type of glass and used for steam-turbine blanket covers retained from 30 per cent to 40 per cent of their original tensile strength after 12 days next to a hot plate maintained at 900 degrees fahrenheit (482 degrees centigrade). This is about the same loss in strength as shown in figure 1. The significant thing, however, is that even after this treatment, the glass cloth is stronger than cotton and asbestos are with no heat treatment.

Messrs. Louis and Moses bring up the point of deterioration due to vibration. We know definitely that if this is an inherent weakness in Fiberglas insulation, it can be proved only after a longer period of time than Fiberglas-insulated apparatus has been in operation; for as far as is known, no failures have been attributable to vibration.

Unfortunately we have at the present time no data to compare directly with the interesting curves presented by E. L. Lotz. However, we have measured the 60-cycle power factor of a number of different samples of varnished cotton and varnished glass cloth at room conditions, and have found no cotton sample whose power factor was lower than 13 per cent nor any glass sample whose power factor was higher than 7 per cent.

So far as we know, no impulse tests, as Mr. Dissmeyer has suggested, have been made. As far as the reinforcement of the dielectric strength of the paper insulation in transformers is concerned, untreated glass could offer little; but varnished glass should provide much greater dielectric strength and resistance to the effects of corona. With reference to the "wicking" of varnish in glass-covered coils, there seems to be no difficulty. In fact, although coil manufacturers are naturally loath to disseminate such information, there is reason to believe that some of them consider that a fewer number of dips are necessary for some types of glass-insulated coils than for other types of insulation.

Temperature Limits and Characteristics of Mica as Used in Conjunction With Class "B" Insulation

By ROBERT H. SPRY
ASSOCIATE AIEE

THE TYPE of class *B* insulation referred to in this paper is primarily intended for small and medium sizes of general purpose motors, generators, and associated equipment.

Of the many different varieties of micas found in the world's mineral deposits, only two are used for electrical insulation, namely, muscovite and phlogopite. Commercial sources of supply are found mainly in India, Madagascar, Africa, Brazil, and Canada. The mica-bearing veins are very erratic in their occurrence; in some localities they are found on and near the surface, while in others, they are several hundred feet below the ground. The yield of commercial mica obtained per ton of rock may be as low as one per cent. In general, the area of rough mica slabs varies from approximately 2 square inches to 50 square inches. However, in exceptional cases, pieces are found as large as three feet by four feet. After the extraneous rock and other incrustations are removed from the slab of mica, it is then split into thicknesses of approximately one-eighth inch—commercially termed "blocks." The blocks are further classified for quality and graded for size by experienced native labor. Details regarding the various recognized qualities and gradings may be found in ASTM method *D*-351-37*T*.

Muscovite mica is often referred to as India mica, white mica, ruby, potassium mica, etc. Clear muscovite films have a dielectric strength of approximately 3,000 volts per mil to 900 volts per mil for thicknesses of 0.002 inch to $^1/_{16}$ inch respectively at 25 degrees centigrade. For temperatures of 300 degrees centigrade the dielectric strength is roughly equal to 75 per cent of the stated values. The power factor varies from 0.0001 to 0.0008 at 25 degrees centigrade for a frequency range of 60 cycles per second to 1,000 kilocycles per second. The dielectric constant under the same conditions is 6.5 to 8.5.

Phlogopite mica, which is more universally known as amber or silver mica is softer physically than the muscovite micas. Selected grades of phlogopite mica may be operated at temperatures of 800 degrees centigrade to 900 degrees centigrade as compared to 400 degrees centigrade to 500 degrees centigrade for muscovite mica. Its dielectric properties are, however, poorer than the muscovite micas, the dielectric strength being approximately 70 per cent of the values quoted above and the power factor has a rather wide spread of 0.003 to 0.09.

The most important characteristic of mica which permits its wide use as a dielectric is its basal cleavage. Films or splittings as thin as 0.0003 inch may be produced by skilled natives. Specifications of commercial splittings range from 0.0006 to 0.0013 inch in thickness. By using these thin films or splittings, a high degree of flexibility is obtained for such applications as coil wrappers and molding micanite plates.

The physical limitations of the size or area of the natural micas are overcome, to a large extent, by assembling the films into large sheets with the aid of suitable binders. A wide variety of types of "built-up" or Micanite plates and wrappers are obtained by combinations of binders, adhesives, carriers, and heat and pressing operations. The following general classifications of micanite plate and other combinations of mica fall within the AIEE definition of class *B* insulation:

Group I. Hard, rigid sheets for commutator segments, etc., contain a minimum percentage of binder (shellac or Glyptal) which has been polymerized to prevent exuding of the binder and slippage of the mica films when subjected to heat and pressure. Organic-bonded heater plates for resistance elements that are mechanically supported also come within this group.

Group II. Hot molding plates for cylinders, vee rings, slot cells, etc., containing from 10 per cent to 20 per cent of shellac or Glyptal binders which are undercured to facilitate molding and forming operations. Additional heat treatment or curing cycles are required on this type of plate to make it suitable for supporting mechanical loads at elevated temperatures.

Group III. Cold flexible plate for slot, phase, and ground insulation can be formed readily at room temperatures. The binder is essentially composed of nondrying oils, plasticizers, and natural and synthetic resins. It, therefore, should not be used under high mechanical loads where stability is of paramount importance.

Group IV. Composite Insulation. The mica splittings are usually backed with, or sandwiched between, carriers such as capacitor tissue, silk, cotton, cellulose acetate, Fiberglas, asbestos, slot papers, or varnish-coated cloths. The carriers provide sufficient mechanical strength to enable the mica films to be applied directly to the conductors and coils. The binders used in these combinations are comparable to those listed in group III with the addition of asphalts and pitches.

The percentage of mica by weight in the composite insulations varies over wide limits, depending upon the materials used. For the thinner carriers such as capacitor tissues and silk, the average quantity of mica is in the order of 65 per cent, the remainder being binder and carrier.

In the past decade, numerous inorganic materials have been tried for binders in order to increase the operating limits of electrical apparatus. The apparent limitations of all the inorganic binders are the high heat treatments or temperatures required to make the binders chemically and electrically stable. Following such heat treatments, inorganic binders lose their flexibility and become, in most cases, a brittle, crystalline structure. Therefore inorganic-bonded mica is limited to simple rigid forms such as plates and cylinders. The large number of plasticizers and synthetic resins now available has improved the retention of flexibility in organic binders and varnishes. A specific example of the improvement in the heat resistance of varnish films within the last six years is represented by the following data which we have collected on varnished cambric cloth.

The test procedure in determining the respective heat resisting properties of the varnish film is accomplished by hanging narrow tapes (approximately one inch in width by six inches to ten inches in length) in ovens maintained at temperatures of 100 degrees centigrade and 125 degrees centigrade plus or minus 2, degrees, respectively. Samples are withdrawn at regular intervals and bent around a one-eighth-inch diameter mandrel. A checking or cracking of

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the varnish film is considered as the end point or failure and the total number of hours is recorded for the particular sample. In 1932 the average life of varnished cloth was in the order of 500 to 600 hours at 100 degrees centigrade, and 100 to 150 hours at 125 degrees centigrade. Today the special varnished cloths of comparable thicknesses are capable of withstanding in the order of 2,500 to 3,000 hours at 100 degrees centigrade, and 350 to 450 hours at 125 degrees centigrade. By sacrificing some of the electrical properties, the heat resistance can still be greatly improved on certain grades of varnished cambric cloth. It is recognized that in view of the fact that the entire surface of the varnish film is exposed to the oxidizing and/or polymerizing action of the atmosphere, the rate is considerably greater than would be encountered in practical applications of multiple layers. Therefore a correlation between test data and practical experience must be made for each condition encountered.

Because of basic differences between varnish-coated products of class *A* insulation and the combinations of mica and coils for class *B* insulation, it is difficult to establish reliable test methods for determining heat-resisting properties. The binders for the mica products must first have a certain minimum degree of adhesion to hold the splittings in place in addition to the other electrical and physical requirements; second, due to the overlapping laminated structure of the mica films, tests such as tensile strength, tearing, bending, etc., are unreliable because they depend essentially upon the carrier and not the over-all combination of the insulation.

It appears that the only dependable and satisfactory way in which to determine the aging characteristics and temperature limits of class *B* insulation is to apply them to the individual unit of electrical apparatus where such variations as heating and cooling cycles, expansion and contraction, vibration, high and low humidities, corrosive vapors and gases, etc., are present.

Doctor T. S. Taylor's paper on "Repeated Thermal Expansions and Contractions and Their Effect Upon Long Armature Coil Insulations" (AIEE, 1924) is the only specific data that can be found on this subject. A model of four slots having an over-all length of 110 inches was built up from punchings. Ventilating ducts $\frac{1}{2}$ inch and $1\frac{1}{4}$ inches wide were included in an attempt to duplicate present engineering practice. Eight coils, two per slot, were insulated with various types of class *B* mica-tape insulation. The model was subjected to heating and cooling cycles with increasing temperatures of 75, 100, 130, and 160 degrees centigrade for a total of some 11,500 periods. Following each series of tests a potential of 37,000 volts was applied from conductor to ground with no breakdowns. At the duration of the experiment, an examination of the coils disclosed that the carriers and binders were completely destroyed in and near the several air ducts and that considerable deterioration had occurred in the slot section. I refer to this paper somewhat in detail for predicating the following comments.

First, for the relatively short period of time consumed in making these observations as compared to several years of operating life of the normal motor, temperatures in the order of 160 degrees centigrade were sufficient to destroy the organic carriers of the mica films and the bonding properties of the varnishes.

Second, in and near the air ducts, where the insulation was not mechanically supported, and also subjected to a higher rate of oxidation, there was excessive deterioration and swelling of the composite structure.

Third, the dielectric properties of the mica were not affected as evidenced by the high potential tests.

Fourth, in the absence of vibration and continuous voltage stresses, the individual factors of expansion and contraction of these long coils did not have a deleterious effect upon the insulation.

If the model had been subjected to vibration and electrical stresses comparable to conditions found in practice, it is quite possible that some of the mica films would have shifted, particularly those in and near the air duct; also there would no doubt have been added deterioration due to ionization in the spaces created by the volatilization and disintegration of the binder and carrier.

Thermal conductivity of a given insulation and indirectly its life, is a function of its density or compactness. Therefore, if the best composite insulation now being made should be loosely applied and poorly impregnated, its ability to withstand elevated operating temperatures would be seriously reduced. This factor alone probably accounts for the large deviations in the operating life of electrical apparatus. Any time-temperature relationships should also take into consideration the compactness of the coil as well as its intimate physical contact with the slot walls or other supporting and heat-conducting mediums.

If it were possible to analyze failures on the basis of those due to vibration versus pure dielectric breakdown, we would no doubt become more critical and active in establishing standards for the former. The swelling or protruding of the coil insulation due to the normal coefficient of expansion of the composite structure and possible volatilization of the bond at elevated temperatures in the air ducts and at the end of the slots creates a localized mechanical problem. Continued vibration may be sufficient to pulverize both the carrier and mica at these areas. At the higher operating voltage stresses the swelling of the coils may also introduce ionization in the coil structure.

Where space factor or the minimum frame size for a given horsepower output is limited such as, railway motors, the AIEE have established separate and special operating temperature limits for the class *B* insulation. The permissible hot spot temperature has been increased from 125 degrees centigrade to 175 degrees centigrade. Quite frequently the heat generated by the I^2R losses in starting and the core losses due to higher operating flux densities exceed 175 degrees centigrade on motors having insufficient thermal capacity. Unless some emergency exists, the duration of these excessive temperatures is for relatively short periods of time and therefore gives a reasonable operating life for the motor. The deteriorating effects of the higher operating temperatures and the extreme conditions of vibration and weather on the insulation of railway motors is in most cases of secondary importance to the maintenance of time schedules. To obtain a reasonable operating life at these temperatures the insulation must be essentially inorganic such as mica and asbestos or glass fibers. Special attention must be given or changes in design made to see that the mica splittings in the entire coil structure are mechanically held in place and prevented from slipping. The common flat iron or heating element employing organic-bonded micanite heater plate is a typical and comparable example showing that if the mica is mechanically held in place the operating temperatures can be materially increased above the present AIEE temperature limits.

The mica splittings used in class *B* insulation have two outstanding physical advantages over other flexible inorganic materials such as asbestos and glass fibers. First, due to the solid and nonporous structure, the surface leakage path is tremendously increased. Second, moisture or water is adsorbed by the laminations of the mica splittings and does

A Discussion of Proposed ASA Transformer Standards

By R. T. HENRY
FELLOW AIEE

THE proposed American Standards Association standards for transformers, regulators, and reactors which are about to be circulated for a trial period involve several departures from previous standards.

The temperature rise has been separated from the ambient and total temperatures. It is the temperature rise which determines the amount of material required and therefore the rating; whereas the ambient and total temperatures are involved only in the operation and life of the insulation and have little or nothing to do with the rating.

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Insulation levels have been established in zones for dielectric tests instead of basing the tests on rated voltage. These insulation levels are based on the level of protection available in the various voltage classes.

The proposed standards include impulse tests in addition to the low-frequency dielectric tests. These impulse tests are specified in kilovolts instead of gap spacings.

The insulation strength of transformers, regulators (except induction type), constant-current transformers, and instrument transformers have been co-ordinated, thus providing the same insulation strength for various types of apparatus of corresponding voltage ratings. The insulation levels for both power and distribution transformers have been made the same for 23 kv and above.

The test code has been enlarged and brought up to date and now includes complete instructions for making the various tests on transformers, etc.

The proposed guides for operation of transformers recognize the fact that the life of insulation depends not only on the temperature but on the duration of such temperature as well and that while transformers can be operated with a copper temperature of 95 degrees centigrade (55 degrees centigrade rise at 40 degrees centigrade ambient) for limited periods without serious damage, continuous operation at such temperatures would reduce the life of the insulation to a few years at best. The recommendations for loading are therefore based on a *maximum* ambient temperature of 40 degrees centigrade but a *daily average* ambient temperature of 30 degrees centigrade.

The guides also recognize that the permissible continuous loading is greater than the rating at low ambient temperatures and less than the rating at high ambient temperatures. In addition, the guides recognize that transformers can carry appreciable overloads for limited periods and the recommendations provide for short-time overloads for recurrent conditions and higher short-time overloads for emergency conditions.

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not materially reduce the dielectric strength because of the nonabsorption characteristics of the individual laminations. The interstices of the asbestos and glass fibers must be filled with a varnish or compound to give additional dielectric strength above that of the air. Until suitable inorganic varnishes are developed, the most logical type of class *B* insulation having the highest over-all electrical and temperature limitations would be one composed of mica splittings and asbestos or glass fibers.

Notwithstanding the apparent improvements in varnishes, binders, and new carriers or base materials, we must recognize that either the electrical or physical limitations of class *B* insulation are still dependent upon *organic* substances and until they are radically changed or supplanted by inorganic binders and varnishes having suitable electrical and physical properties, plus stability at higher temperatures, we must not overlook this factor in proposing changes in general standards for operating-temperature limits of electrical apparatus.

In view of the variables which are so difficult to measure and correlate, any standards of temperature limits must, of necessity, be a compromise between the conservative viewpoint of low operating temperatures, reliability, long life, high efficiency, and the liberal viewpoint of lower first costs by reduction of size, higher operating temperatures, shorter life, reduced efficiencies, higher maintenance cost, and possible shut-downs for major repairs. Several years of operating experience has proved the AIEE standards for class *B* insulation, that is, a maximum hot-spot temperature of 125 degrees centigrade to be a fair and practical compromise.

The available information in regard to time-temperature characteristics of electrical insulation of all types as applied to electrical apparatus, is very meager. It would therefore seem very desirable for both the manufacturers and the operating companies to undertake a definite program for the investigation of this important subject. Any information thus found would be to the mutual knowledge and advancement of our engineering society.

Asbestos and Glass-Fiber Magnet-Wire Insulation

By K. N. MATHES
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MAGNET WIRE may be divided into class *O*, class *A*, class *B*, and class *C*, on the basis of the AIEE temperature ratings.[1] Many types of class *O* or class *A* magnet-wire insulations are in common use. The variety of class *B* magnet wire insulations is, for obvious reasons, much more limited. Different types are listed in table I.

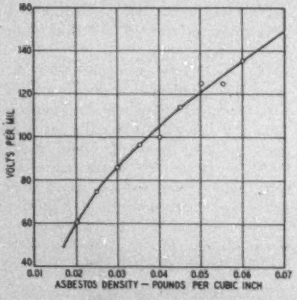

Figure 1. Volts per mil versus density of dry asbestos

Thickness 25 mils

Felted asbestos fiber has been prominent as a class *B* fibrous magnet-wire insulation. The recently developed commercial production of glass-fiber-insulated magnet wire has created considerable interest. This paper is limited to a consideration of the properties and application of these two types of class *B* fibrous constructions.

Class *B* magnet wire is used principally where high temperatures are encountered. The temperature stability of insulation, however, cannot be considered alone as it is qualified by many other factors when considering a particular application. In some cases flexibility may be of first importance and an extremely heat-resistant impregnating material, which may become brittle and crack, cannot be used. Heat resistance may have to be sacrificed in order to obtain the necessary degree of flexibility. Similarly insulation may be subjected to higher temperatures when not exposed to conditions of moisture. It is important, therefore, to study many other properties of a class *B* magnet wire even though the temperature stability may be of primary importance.

Conclusion

The temperature limitations of class *B* magnet wire must be studied in terms of many related factors. The stability of the associated varnish is one of the most important considerations. Where good moisture resistance must be retained, operating temperatures should be restricted to approximately 125 degrees centigrade in order to preserve the varnish film.

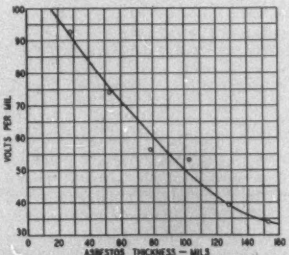

Figure 2. Volts per mil versus thickness of dry asbestos

Density 0.035 pound per cubic inch

Experience has indicated that for many types of service conditions and with the proper material reasonable insulation life can be expected for a range of temperatures from about 125 to 175 degrees centigrade. Of course insulation life decreases rapidly at the higher temperatures. In special applications, which are completely free from vibration and where dielectric requirements are not severe, operation at temperatures above 175 degrees centigrade may be permitted. The designer of electrical apparatus must correlate these factors to suit his particular problem.

The advantages of asbestos-insulated magnet wire in class *B* operating service are well established.

Glass-fiber magnet-wire insulation is finding an important field of use in electrical apparatus. The superior electrical properties and possibility of decreased space factor are important in many applications, and further improvements can be expected as development proceeds. Glass-fiber insulation is still too new to permit the presentation of extensive information concerning its life under service conditions.

Properties of Unvarnished Asbestos and Glass Fiber

In the analysis of any electric insulation wherein several components comprise the whole, it is essential to give careful consideration to the selection of these components and evaluate their individual characteristics.

The term "asbestos" is a commercial term applied to any mineral which can be readily separated into more or less flexible fibers. Asbestos is a heat-resisting nonmetallic mineral silicate including two groups—the serpentine or chrysotile group (hydrous silicates of magnesium) and the amphibole group (metasilicates of magnesium, calcium, iron, sodium, and aluminum, with a little water of hydration).

Table I

Continuous (enamel)	Inorganic oxide bound with organic binder[2]	Inorganic material coated with organic material[2]
Ribbon	Asbestos paper	Paper or cloth baked mica tape
Fibrous	Varnished asbestos fiber	Varnished glass fiber

Table II

Property	Asbestos	Glass Fiber
Fusing point (degrees centigrade)	1,550[4]	About 700
Yield point (loss of resilience) (degrees centigrade)	No significance	550 to 600
Dehydration temperature* (degrees centigrade)	Over 385	None
Stress relieving temperature (degrees centigrade)	No significance	Above approximately 150
Acid resistance	Fair	Good (attacked by hydrofluoric)
Resistance to corona	Decomposes slowly producing magnesium nitrate	Unaffected

*Loss of water of hydration (chemically combined water).

A paper presented under the auspices of the AIEE committee on electrical machinery at the AIEE winter convention, New York, N. Y., January 23–27, 1939.

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1. For all numbered references, see list at end of paper.

Chrysotile asbestos is the variety commonly used in the electrical industry. Due to the fineness of fibers, and their strength and flexibility, it can be carded for felting or spun into roving (a soft rope-like material) for application to wire in much the same manner as other textile materials.

The flexibility of asbestos is closely related to the combined water content, which, in the chrysotile variety, averages 14 per cent and accounts for its superiority to all other types. Flexibility is maintained consistently at all temperatures below 385 degrees centigrade.[4] At higher temperatures the water of hydration is gradually driven off and the fibers can be easily pulverized. From a consideration of heat resistance alone, it can be said therefore, that asbestos possesses ample margin for all magnet-wire applications in motor and generator armature and field coils.

Emphasis must be placed on two factors; magnetic iron and surface impurities (conducting salts present on the surface of all asbestos fibers). Magnetic iron cannot be separated from the fiber commercially and extreme care must be used in the selection of a source having a low content (0.50 per cent maximum of magnetic iron for nonferrous grades) which is so generally dispersed that the possibility of large particles, causing

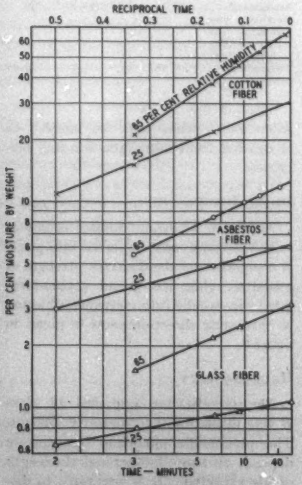


Figure 3. Increase in per cent moisture versus minutes at 25 per cent and 65 per cent relative humidity, at 25 degrees centigrade

Samples conditioned 16 hours at 150 degrees centigrade

grounds between turns in apparatus coils, is remote. The same care must be exercised in selection to obtain material free from surface conducting salts since it has definitely been proved that the dielectric strength is not so much dependent upon the basic asbestos as on the amount of surface impurities present which have a great affinity for moisture.

The dielectric properties of untreated dry asbestos fiber plotted as a function of density and thickness are illustrated in figures 1 and 2.

Asbestos fiber for electrical insulation is graded as number 1 or number 2 depending upon the average length as determined by screen test. The asbestos fiber is mixed with cotton to facilitate textile operations, 10–15 per cent being the usual average content for magnet-wire materials. The fiber is processed into laps for direct application or spun into roving (either with or without a cotton core) and wound on suitable packages for spiral wrapping on the conductor.

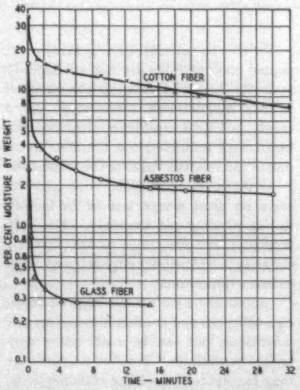


Figure 4. Decrease in per cent moisture versus minutes at 50 per cent relative humidity and 25 degrees centigrade

Samples conditioned at 100 per cent relative humidity and 40 degrees centigrade

Glass fiber is a synthetic material of definite composition and quality. The commercial production of glass fiber has been described previously.[5] Textile fiber glass may be classified as staple fiber (6 to 8 inches long) and continuous filament. The fibers are 0.00025 inch in diameter or smaller. Because of the enormous surface area of the fine glass fibers, severe weathering and low electrical surface resistivity may be experienced unless the fibers are drawn from excellent electrical

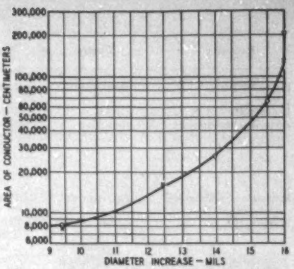


Figure 5. Maximum insulation increase for round double-cotton- or double-glass-insulated magnet wire

⊙—National Electrical Manufacturers' Association values for cotton

glass. An alkali-free glass has been developed for electrical purposes which has high surface electrical resistivity and good resistance to ordinary moisture conditions. The alkali-free glass may disintegrate under some steam conditions and is not as stable as asbestos in this respect.

The surface of the glass fiber is particularly sensitive to cutting or nicking by adjacent fibers and must be protected by a sizing material possessing proper lubricating and binding properties. The sizing material used at present contains hygroscopic materials which impair the electrical and physical properties. In addition, the sizing is somewhat corrosive to copper and is not truly compatible with most insulating varnishes.

Although the glass fiber does not permit volume absorption of moisture, it cannot strictly be called nonhygroscopic since electrical properties may be damaged by moisture picked up in the following ways:

1. Adsorption on the glass-fiber surface.
2. Absorption in sizing material.
3. Capillary action between fibers or threads.
4. Capillary action between fiber and surrounding varnish.

The per cent regain and loss of weight for unvarnished cotton, asbestos, and glass fiber as a function of time at various humidities are given in figures 3 and 4. The potential advantages of glass fiber can be emphasized by comparison with the asbestos fiber which is truly a bundle of extremely fine fibers with surfaces contaminated by conducting salts.

For use as wire insulation, both staple and continuous glass fiber are used. Staple-fiber yarn is tightly spun, bonds together well because of its relatively rough finish, and can withstand greater

Table III

Property	Cotton	Asbestos	Glass
Space factor	See figure 5	Same as double cotton	Same as cotton (One half that of cotton with special glass)
Uniformity	Good	Fair	Good
Abrasion resistance	Superior	Adequate for coil applications	Inferior to asbestos for sharp-edged surfaces but may be superior to asbestos for smooth rubbing surfaces (adequate for coil applications when proper consideration is given to the tension device)
Impact resistance (see figure 6)	Fair to good	Fair	Very good
Flexibility	Good. Double wrap superior to single wrap	Fair, for round wire. Poor, for large rectangular sizes	Good. Double wrap superior to single wrap. Slightly inferior to cotton
Stiffness due to insulation (Important in small wire sizes)	Less than single glass	Less than single glass	Single but not double wrap exhibits considerable stiffness
Bonding (depends somewhat on varnish treatment)	Good	Good	Fair to good. Staple-fiber insulation bonds better than continuous filament

elongation than continuous-filament yarn. In contrast, continuous-filament yarn can be softly spun, yet is stronger, more resistant to abrasion, and smoother in appearance than staple-fiber yarn. Continuous-filament yarn is available in much finer sizes than staple-fiber yarn, which is used where heavy insulation thicknesses are desired and varnish saturation is difficult to secure.

A number of other basic properties listed in table II are of interest in the comparison of asbestos and glass fiber.

Properties of the Insulated Wire

In brief, two principal factors are of interest in connection with magnet wire:

1. The ease of handling and the ability to withstand the factory winding operation and electrical tests.

2. The design characteristics (temperature rise, space factor, etc.) which will allow a reasonable insulation life under service conditions.

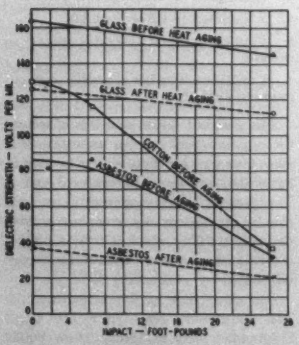


Figure 6. Dielectric strength versus increasing impact

Up to the present time generally accepted test methods are not available to evaluate completely the relative merits of fibrous magnet-wire insulations. As a result, practical experience must be combined with improved test methods to indicate the relative value of the insulation.

In many cases magnet wire may receive its most severe test in the factory during winding and assembly. Not only flexibility and resistance to abrasion but elongation and impact strength may be of extreme importance.

Laboratory tests cannot hope to duplicate all types and combinations of service conditions, but can be made under controlled conditions. Tests on magnet wire may be divided into three classifications:

1. Tests on the wire itself.

2. Tests on built-up coils to represent conditions present in various types of apparatus.

3. Tests on apparatus.

Each method of test has certain advantages and serves as a guide post in the over-all analysis. Most laboratory tests are accelerated—one or more conditions are made extreme in order to shorten the time of test. Accelerated test results must be carefully interpreted and only relative results can be expected. Long time tests (extended over a period of months with a variety of conditions, such as temperature, moisture, and voltage cycles) have much more significance in terms of actual operating service. Even long time test results serve only to indicate relative values of different types of insulation and cannot be extrapolated to indicate the absolute life under operating conditions, particularly since a combination of conditions not present in the test may be the deciding factor.

Once in place, insulation must meet a combination of various types of service conditions. The most practical criteria of a particular wire insulation comes from an analysis of actual operating results. The problem, however, sometimes is complicated by the difficulty of determining, after a failure in the field, which portion of the system failed first and the reason.

Various physical properties of cotton-covered and varnish-treated asbestos- and glass-fiber-insulated wire are compared in table III.

Flexibility

When bent or stretched, a felted insulation such as asbestos exhibits an uneven thinning of the insulation in certain spots. In contrast, a wrapped fiber insulation such as glass fiber spreads more evenly—the parallel threads, when properly applied, tend to separate slightly and maintain a constant space factor. The superior flexibility of a wrapped-thread type of insulation becomes of practical importance when large wires must be bent on short radii without damage or

Table IV

	Abrasion Resistance (Average Turns per Mil of Insulation Thickness to Cause Failure)			
	Asbestos		Glass Fiber	
	Large Wire	Small Wire	Large Wire	Small Wire
As received	35	44	19.2	89
Exposed one month to 170 to 180 degrees centigrade	0.48	25	1.1	5.9

when small wires may be subject to elongation from automatic winding machines.

Impact Resistance

Ability to withstand impact is important when wire must be forced into place. A comparison of the dielectric strength of asbestos-, glass-fiber-, and cotton-insulated wire wound into coils and subjected to increasing direct impacts is given in figure 6.

Heat Stability

The quantitative appraisal of class *B* wire insulation is particularly difficult. The permissible operating temperature depends on many factors and the length of life expected. It is necessary to discuss the relative effect of exposure to high temperatures on the physical and dielectric properties.

Deterioration of physical properties may be even more important than im-

paired electrical properties. It is precisely this factor which is also most difficult to measure. The effect of vibration and conditions caused by temperature cycles encountered in service cannot easily be duplicated in the laboratory. Abrasion and impact tests are made which may serve as an indication of resistance to such conditions in service. Table IV indicates the effect of temperature on the relative resistance of asbestos- and glass-fiber-insulated wire to the abrasion of smooth, tungsten-carbide rods in the form of a rotating cylindrical cage.

By referring to figure 6 again the effect of heat aging can be observed by comparing the position of the dotted to the solid curves. Glass is superior to asbestos in this respect.

Table V indicates the relative effect of exposure at 170 to 180 degrees centigrade on the dielectric strength of asbestos- and glass-fiber-insulated magnet wire. It is important to recognize that these tests were made on wire placed in a well-ventilated oven, and that aging occurs much more rapidly than when the wire is sealed deep in apparatus where oxygen is largely excluded. A month of exposure of 170 to 180 degrees centigrade was sufficient to damage the varnish film and thereafter the rate of deterioration was slower.

Both asbestos and glass must be considered as physical spacing mediums. Failures or loss of dielectric strength under high heat and moisture conditions are primarily failures of the treating materials used in the insulation system.

Moisture Resistance

Insulation resistance is one accepted criterion of the effect of moisture on insulation in coils. The average insulation resistance between parallel wires of wound coils is plotted as a function of time at 100 per cent relative humidity and 40 degrees centigrade in figure 7. These coils were wound to duplicate field coils and were completely varnish treated. The upper curve indicates the possibility of improvement in the moisture resistance of glass insulation. In this case the original sizing was removed from the glass fiber and replaced with an improved material before varnish treatment.

Application of Class B Magnet Wire

No sweeping conclusions should be drawn from this compilation of data. Although tests show glass-insulated wire as definitely superior to asbestos in electrical properties, the mechanical properties after exposure to high temperature may be inferior in some respects. Since glass-fiber insulation is so new, only preliminary service data have been collected; years of experience have proved the serviceability of asbestos insulation.

Keeping in mind the effect of temperature on various properties, it is possible to divide approximately the types of application for both asbestos- and glass-fiber-insulated magnet wire into three divisions based on operating temperatures as listed below.

1. Temperatures up to 125 degrees centigrade—For reasonable life the film of the binding varnish is not seriously impaired and relatively good moisture and physical and dielectric properties are retained.

2. Temperatures from 125 to 175 degrees centigrade—Film structure of varnish deteriorates but sufficient varnish may remain to act as a binder. Moisture resistance, electrical and physical properties are somewhat impaired.

3. Temperatures above 175 degrees centigrade—The binding varnish is destroyed. Electrical and particularly physical properties are considerably impaired.

In most cases operating temperatures above 175 degrees centigrade are impossible because vibration and wear destroy the insulation mechanically.

It is perhaps too early to compare extensively the field of application for asbestos- and glass-fiber-insulated magnet wire. For the larger size of wires, the increased cost of glass-fiber insulation must be justified, either by increased quality or by saving in over-all cost.

The following two factors should be studied:

1. Possibility of decreased space factor, resulting in smaller motors or increased copper area with the same slot space and resulting greater output or efficiency.

2. Possibilities for saving in labor.

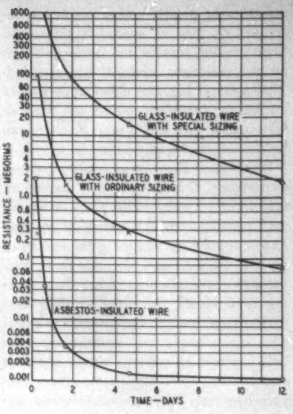


Figure 7. Electrical resistance versus days at 100 per cent relative humidity and 40 degrees centigrade

Method of Manufacture

A commonly used method of asbestos magnet-wire manufacture consists of wrapping asbestos roving spirally around the conductor, applying compound, and removing the excess with suitable polishing dies. With this method, uniformity of the insulation is limited by the uniformity of the roving which, in the smaller sizes, is difficult to control. Low production speeds result because of lack of strength when the finer sizes of roving are used, and this method is generally limited to large wires with insulation increases greater than for double cotton.

A method whereby the asbestos is felted on the wire was introduced in recent years which permits the application of carded asbestos directly to the wire, giving a homogeneous, intertangled mass of asbestos at all points on the conductor. Improved space factor, greater density of insulations, more uniformity, and reduced cost are achieved. Wire sizes from number 30 to 4/0 can be readily insulated

Table V

	Dielectric Strength (Volts Per Mil)		
	Asbestos Average*	Single Glass Average*	Double Glass Average**
Wire as received, tested at 25 degrees centigrade, 50 per cent relative humidity	87.5	191	170
Wire as received, and exposed 16 hours at 40 degrees centigrade, 100 per cent relative humidity	29.8	105	85
Wire exposed one month at 170 to 180 degrees centigrade, tested at 25 degrees centigrade, 50 per cent relative humidity	53.4	146	114
Wire exposed one month at 170 to 180 degrees centigrade, exposed 16 hours at 40 degrees centigrade, 100 per cent relative humidity	11.3	41	32

*Average of 20 results on different sizes of wire from 0.0201 to 0.114 inch.
**Average of five results on 0.72-inch wire.

maintaining double cotton insulation increases or less in special applications. With greater density and uniformity improved dielectric strength has resulted. This method has one deficiency—loss of insulation flexibility on larger sizes of rectangular wire which may be overcome by the use of proper treating materials.

Since glass fiber is so readily twisted into strong, fine thread, it is applied in this form to wire. The yarn is wound with parallel ends in a universal winding and is applied by wrapping the ribbon of parallel ends around the wire as it runs through the wrapping machine in a manner very nearly the same as that used with cotton or silk. Care is used to eliminate sharp edges and unnecessary rubbing surfaces in order to reduce abrasion and friction to a minimum. Since the yarn has very little extensibility, the insulating process must be very precise to avoid yarn breakage.

Staple glass fiber has been applied to wire directly as it comes from the fiber-making machine in the form of a wrapped sliver of parallel filaments. Wire insulated in this way does not have the density nor uniformity of a wrapped-thread type of insulation.

Fibrous-insulated class *B* magnet wire must be compound or varnish treated in order to attain sufficient abrasion resistance to be suitable for winding operations. An adequate treatment should give the wire the following characteristics:

1. Good abrasion resistance—obtained by adequate bonding, penetration, and filling of the interstices between fibers.
2. Hard and smooth surface film.
3. Good flexibility.

These desirable qualities are functions of the following factors:

1. Type and nature of treating varnish or compound.
2. Method used to secure penetration.
3. Temperature and degree of baking.

Because so many factors are concerned, no one exact method can be described at this time for varnish or compound treatment of fiber-insulated wire.

References

1. AIEE Standard No. 1, April 1925.
2. United States Patent 2,022,827 to Vega Manufacturing Company.
3. British Patent 380,426, 1932, A. G. Hovey, British Thomson-Houston Company.
4. TEXTILE RESEARCH (a book), J. M. Weaver, Chapter 15, Asbestos Textile Industry.
5. FIBER GLASS—MECHANICAL DEVELOPMENT, J. H. Plummer, *Industrial and Engineering Chemistry*, volume 30, July 1938, page 726.

Lightning Performance of 110- to 165-Kv Transmission Lines

A GREAT MANY papers have been presented in recent years on the subject of lightning as it affects the electrical industry and particularly transmission lines. Quite a few of these papers have dealt with the lightning performance of high-voltage lines in service covering individual systems in various sections of the country.

A committee paper was presented in 1935 on "Lightning Performance of 220-Kv Lines" [1] which summarized and discussed the records of some 19 lines in the 220-kv class comprising practically all lines of that voltage operating in the United States and Canada. This type of record with its broad inclusive coverage of lightning performance of lines was received with so much favor that it was recommended by the AIEE power transmission and distribution committee that the lightning and insulator subcommittee collect and present similar records giving the lightning performance of high-voltage lines in the general voltage classification of 132 kv. The data and discussion presented in this paper have resulted from the above situation.

Scope and Plan

In collecting data on these higher-voltage lines, it was decided to include the transmission voltage range from 110 kv up to 165 kv, inclusive, for lines operating in the United States and Canada.

The data were obtained by sending a questionnaire to companies who either operated or had under their control lines in the above classification. The questionnaire included 71 questions which were designed to give principally what was considered important information on line construction and line operation and to bring out outstanding features which might throw some light on the lightning performance of these lines over the past ten years. Some information not directly connected with the lightning performance of the line was requested and has been included in the data presented herewith.

Each company was asked its opinion as to whether the ten-year lightning performance of each of its lines was satisfactory, and if not, what types of improvement were being considered. The detailed questionnaire with accompanying prints of typical towers and counterpoise designs is too lengthy to reproduce here, but the pertinent data received has been tabulated, analyzed, and discussed.

Extent of Lines Reported

The questionnaire was sent out to 35 companies in the United States and Canada. Operating records and data were received from 24 companies. Four companies reported that they had no lines in the voltage range indicated and seven companies failed to send in an answer. It will therefore be seen that of the 35 companies contacted, the response to the committee attempt to get information in this way has been most gratifying, replies having been received from 70 per cent of the companies.

It is interesting to note that of the 24 companies sending in data, records have been received on lines operating in 20 states in the United States and also from Canada. The lightning severity as shown by the isokeraunic level where these lines operate ranges from 22 storms to 68 storms per year, that is a ratio of slightly over three to one.

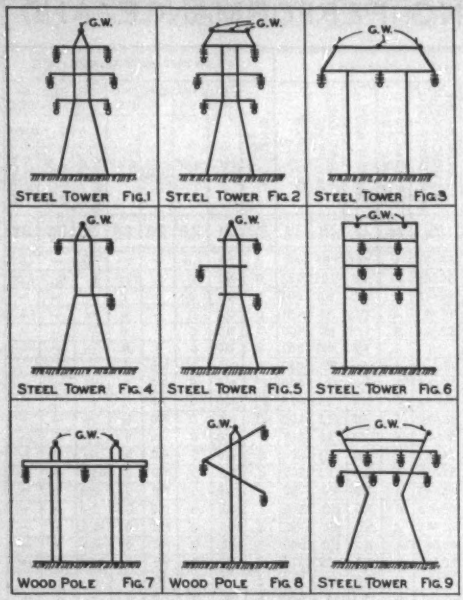
Table I gives in some detail the character of the transmission lines on which data were obtained. The table shows that the records cover 7,140 miles of line (right of way) of which 3,890 are of two-circuit, steel-tower construction; 1,725 of single-circuit steel construction; and 1,526 of single-circuit, wood construction. Fifty-four per cent of the mileage is of 132-kv construction; 31 per cent of 110-kv rating; and the balance distributed among the other voltage classes.

Paper number 39-60, prepared by the lightning and insulator subcommittee of the AIEE committee on power transmission and distribution, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE winter convention, New York, N. Y., January 23–27, 1939. Manuscript submitted November 25, 1938; made available for preprinting December 30, 1938.

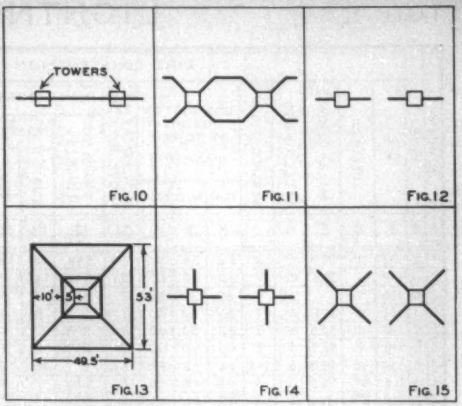
Personnel of AIEE lightning and insulator subcommittee: Philip Sporn, *chairman;* H. A. Frey, I. W. Gross, D. C. Jackson, Jr., W. W. Lewis, J. T. Lusignan, F. W. Packer, and C. F. Wagner.

The committee wishes to acknowledge the wholehearted co-operation of the contributing companies who have generously contributed data to make this report possible and their prompt response in answering the questionnaire on which the data presented in this report were based. It also acknowledges the assistance of G. D. Lippert of the American Gas and Electric Service Corporation in preparing the data received into suitable form for analysis as given herein.

1. AIEE Lightning Reference Book, page 1272.



Figures 1–9. Typical transmission structures



Figures 10–15. Typical counterpoises

All the lines operate at 60 cycles unless otherwise noted in footnotes 1 and 2 of the table.

Presentation and Discussion of Data

It has not been possible to include all the data received as a result of the questionnaire, but the major part of it, particularly that which covers the lightning characteristics of the line and its lightning performance, has been correlated and tabulated in table II. The names of the companies and lines are given by symbol only as a result of a specific request by a few companies that company name and line be withheld from publication.

While replies to the questionnaire were in most cases complete and carefully prepared, in a few cases some questions were apparently misunderstood with the result that the data submitted presented some difficulties in interpretation. However, such instances are few and it is believed that any errors of interpretation placed on the data sent in are of minor importance.

Tower and Counterpoise Configuration

In figures 1 to 9 are given the typical tower structures in use as tabulated in column 7. Likewise, figures 10 to 15 give types of counterpoise configuration, where used, as listed in column 21 of table II.

Ground Wires

The effect of ground wires in reducing lightning outages is shown both in table III and figure 16. From table III it appears where no ground wire is used, single-circuit steel lines show an average of 29.8 outages per hundred miles of line per year; with one ground wire, the outages figure becomes 9.8; and with two ground wires 7.0. The same general type of reduction is shown for wood-pole construction although the figure of 0.44 outages for the single-circuit, wood line with one ground wire is probably questionable for comparison purposes as it includes the record of only one line.

The benefit in going from one ground wire to two is clearly indicated in table III where the outages on two-circuit steel lines drop from 7.1/4.2 to 5.2/3.5 as the ground wires are increased from one to two. The figures separated by the slant indicate outages per hundred miles of line per year, the first figure before the (/) being for single-circuit outages and the second figure for two-circuit outages. These figures for two-circuit steel tower lines give a ratio of 1.36 for single-circuit outages and 1.20 for double-circuit outages as between the one-ground-wire and the two-ground-wire arrangement. For single-circuit steel-tower lines the ratio

Table I. Miles of Three-Phase Line (Right of Way)

Wood-Pole and Steel-Tower Construction

Line Kilovolts	Single Circuit		Double Circuit		Total
	Wood	Steel	Wood	Steel	
165				135.2	135.2
154	89.5			28.7	118.2
140		283.3		52.7	336.0
132	593.3	1,076.7		2,181.6*	3,851.6
120	37.6			274.1	311.7
116		37.3		110.6	147.9
110	806.0	326.9		1,107.4†	2,240.3
Totals	1,526.4	1,724.2		3,890.3	7,140.9
		Total wood	1,526.4		
		Total steel	5,614.5		
		Total	7,140.9		

* Includes 31.5 miles of four-circuit single-phase 25-cycle line.

† Includes 171.9 miles of 25-cycle line.

TABLE II

LIGHTNING PERFORMANCE AND

COMPANY	LINE	LINE CONSTRUCTION: K.V.	CIRCUITS	MILES (R.W.)	STEEL - WOOD	STRUCT. (FIG. Nº)	CONDUCTOR HEIGHT AT TOWER MIN.-(FT.) TOP	MID.	BOT.	GR.W. HEIGHT (FT.) ABOVE TOP COND.	INSULATORS: SPACING (INCHES)	NUMBER SUSP.	NUMBER D.E.	CLEARANCE-LINE TO STRUCTURE(IN.) COND. SWING (DEG.)	CONDUCTOR ALUM.-COP.	ARMOR RODS	VIBRATION DAMPERS	AVG. SPAN (FT.)	LIGHTNING PROTECTION: GROUND WIRES	COUNTER POISES FIG. Nº	COUNTER POISES % OF LINE	GROUND RODS PER TOW	GROUND RODS % OF LINE	GR. RES. OF STRUCTURES AVG. BEFORE CP.-GR.	AVG. AFTER CP.-GR.	MAX AFTER CP.-GR.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	A	132	1	82.5	S	3	52	52	52	11.8	5¼	10	12	62/50	A	YES	YES	1000	2	13	68	—	1	7.9	—	18
2	A	110	1	38.8[a]	W	7	30	30	30	5.1	5½	6	7	36/45	A	NO	YES	632	0	NO	0	1	100	91	81.7	260
2	AA	110	1		S	—	30	30	30	8	5½	7	8	42/45	A	YES	NO	645	1	NO	0	0	0	—	—	—
2	B	120	1	37.6	W	7	30	30	30	5.7	5	8	9	42/45	A	YES	NO	491	0	NO	0	—	—	—	—	—
2	C	110	1	35.3	W	7	60	50	40	5.7	5⅛	7	8	38/45	A	YES	NO	460	0	NO	0	—	—	—	—	—
2	D	110	2	52.9	S	2	60	60	60	9	5⅛	8	9	—	C	NO	NO	881	2	NO	0	0	0	—	—	—
3	A	154	2	28.7	S	1-3	36	36	36	12.6	5	10	12	55/—	A	YES[s]	NO	977	1	NO	0	NO	0	—	—	—
4	A	115	2[4]	16.5	S	3	46	46	46	8	5¾	9[s]	9	36/45	C	NO	YES	600	2[c]	NO	0	NO	0	—	—	—
4	B	115	2[4]	30.6	S	3	46	46	46	8	5¾	9[s]	9[s]	36/45	C	NO	YES	600	2[c]	NO	0	NO	0	—	—	—
4	C	115	2[4]	13.2	S	3	46	46	46	8	5¾	9[s]	9[s]	36/45	C	NO	YES	600	2[c]	NO	0	NO	0	—	—	—
4	D	115	2[4]	20.7	S	3	46	46	46	8	5¾	9[s]	9[s]	36/45	C	YES	YES	600	2[c]	NO	0	NO	0	—	—	—
4	E	115	1	19.5	S	3	46	46	46	8	5¾	9[s]	9[s]	36/45	C	NO	YES	600	2	NO	0	NO	0	—	—	—
4	F	115	1	17.8	S	3	46	46	46	8	5¾	9[s]	9[s]	36/45	C	NO	YES	600	2	NO	0	NO	0	460	—	—
8	A	132	2	11.9	S	2	100	87	74	13	5½	9	11	42/45	A	NO	NO	790	2	NO	0	NO	0	2.9	—	—
8	B	132	2	10.9	S	2	100	87	74	13	5¾	9	11	42/45	A	NO	NO	814	2	NO	0	NO	0	9.4	—	—
8	C	132	2[4]	4.5	S	2	100	87	74	13	5¾	9	11	42/45	A	NO	NO	795	2	NO	0	NO	0	10.6	—	—
8	D	132	2	23.4	S	2	100	87	74	13	5½	9	11	42/45	A	NO	NO	840	2	NO	0	NO	0	12.4	—	—
8	E	132	2	28.8	S	2	97	84	71	13	5½	9	11	42/45	A	NO	YES	512	2	NO	0	NO	0	25.8	—	—
9	A	110[b]	2	23.6	S	2	70	60	50	8.5	5⅛	6	8	60/30	C	NO	NO	560	2	NO	0	NO	0	—	—	—
13	A	132	1	79.5	S	1	69	57	45	10	5	10	11	48/45	A	YES	YES[y]	880	1	NO	0	NO	0	—	—	—
13	B	132	1	54.0	S	1	76	64	52	10.7	5	10	11	48/45	A	YES	YES[y]	970	1	NO	0	NO	0	—	—	—
13	C	132	1	26.4	S	3	69	57	45	10	5	10	11	48/45	A	YES	YES[y]	880	1	NO	0	NO	0	—	—	—
13	D	132	1	8.2	S	1	76	64	52	10.3	5	10	11	48/45	A	YES	YES[y]	970	1	NO	0	NO	0	—	—	—
13	DD	132	1	23.9	S	1	75	63	51	10.3	5	10	11	51/45	C	NO	NO	770	1	NO	0	2	100	—	—	—
14	A	132	1	14.8	S	1	76	64	52	9.3	6⅜	9	11	45/45	C	NO	NO	701	1	NO	0	NO	0	—	—	—
15	A	132	1[b]	30.9	S	2	74	61	48	9	6½	8	8	60/30	C	NO	NO	500	(a)	NO	0	2	100	—	3	5
15	B	132	1[b]	27.9	S	2	74	61	48	9	6½	8	8	60/30	C	NO	NO	500	(a)	NO	0	2	100	—	3	5
15	C	132	1	30.9	S	2	81	68	55	10.4	6½	8	8	60/30	C	NO	NO	500	1	NO	0	2	43	—	3	5
15	D	132	1[c]	42.2	S	2	84	71	58	9	6½	8	8	60/30	C	NO	NO	880	(a)	11	3	2	45	—	10	50
15	E	132	1[c]	61.7	S	2	84	71	58	9	6½	8	8	60/30	C	NO	NO	880	(a)	11	3	2	43	—	10	50
15	F	132	1	24.4	S	2	84	71	58	10.4	6½	8	8	60/30	C	NO	NO	880	1	NO	0	NO	0	10	—	—
15	G	132	1	29.7	S	2	84	71	58	9	6½	8	8	60/30	C	NO	NO	880	1	NO	0	2	85	—	10	67
15	H	132	2	36.9	S	2	84	71	58	9	6½	8	8	60/30	C	NO	NO	880	2	NO	0	2	51	—	8	25
15	I	132	1	10.6	S	2	84	71	58	9	6½	8	8	60/30	C	NO	NO	880	2	NO	0	2	56	—	10	30
16	A	110	1	79.4	W	7	43	43	43	—	5½	8	9	31/45	C	NO	NO	509	0	NO	0	NO	0	—	—	—
16	B	110	1	83.7	W	7	49	49	49	10.5	5¼	8	9	—	A	YES	NO	592	2	NO	0	2	100	—	—	—
17	A	132	1	50.3	S	1	70	58	46	8.5	4¼	10	12	47/50	A	NO	NO	588	1	NO	0	NO	0	—	—	—
17	B	132	1	27.9	S	1	70	58	46	8.5	4¼	10	12	37/50	C	NO	NO	608	1	NO	0	NO	0	—	—	—
17	C	132	1	22.4	S	1	70	58	46	8.5	4¼	10	12	47/50	C	NO	NO	612	1	NO	0	NO	0	—	—	—
17	D	132	1	2.94	S	1-2-6	70	58	46	8.5	4¼	10	12	47/50	A-C	NO	NO	588	1-2	NO	0	4	?	—	1.96	4.8
17	E	132	1	22.8	S	1-2	72	59	47	9.5	5¼	9/11	12/14	37/50	C	NO	NO	60[illegible]	1-2	NO	0	4	?	—	3.5	14.1
17	F	132	1	7.9	S	1	72	59	47	9.5	4¼	10	12	37/50	C	NO	NO	[illegible]	1	NO	0	NO	0	—	—	—
17	G	132	1	52.3	S	1-2-6	70	58	46	8.5	4¼	10/12	12/14	37/50	A-C	NO	NO	[illegible]	1-2	NO	0	4	?	—	2.2	14.1
17	H	132	1	76.1	S	1	70	58	46	8.5	4¼	10	12	37/50	A	NO	NO	[illegible]	1	NO	0	NO	0	—	—	—
18	A	132	1	5.8	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	[illegible]	1	NO	0	2-3	(d)	—	—	—
18	B	132	2	18.0	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	[illegible]0	1	NO	0	2-3	(d)	—	—	—
18	C	132	2	18.0	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	690	1	NO	0	2-3	(d)	—	—	—
18	D	132	2	8.9	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	715	1	NO	0	2-3	(d)	—	—	—
18	E	132	1	8.9	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	715	1	NO	0	2-3	(d)	—	—	—
18	F	132	2	9.9	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	710	1	NO	0	2-3	(d)	—	—	—
18	G	132	2	9.9	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	710	1	NO	0	2-3	(d)	—	—	—
18	H	132	2	6.4	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	650	1	NO	0	2-3	(d)	—	—	—
18	I	132	1	6.1	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	675	1	NO	0	2-3	(d)	—	—	—
18	J	132	2	3.1	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	715	1	NO	0	2-3	(d)	—	—	—
18	K	132	2	6.5	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	680	1	NO	0	2-3	(d)	—	—	—

FOR FOOT NOTES SEE END OF THIS TABLE.

CONSTRUCTION OF 110 KV. TO 165 KV. LINES

GRADING & ARC DEVICES[1]	FAULT CLEARING TIME (CYCLES) RELAYS PRIMARY (MIN.)	RELAYS BACK UP (MIN.)	OCB (MIN.)	LINE OPERATION: YEARS IN SERVICE	OUTAGES DUE TO LIGHTNING ONE CIRCUIT / TWO CIRCUIT 1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	AVG. OUTAGES/ 100 MILE OF LINE/YEAR	CASES OF BURNED DOWN CONDUCTORS	CASES OF PROLONGED OUTAGES	LIGHTNING TERRITORY[2]	ISOCERAUNIC LEVEL	OPERATING RECORD SATISFACTORY	CONSIDERING IMPROVEMENTS TO BETTER LINE PERFORMANCE	COMPANY	LINE
28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	1	2
RR	–	INST.	15	7	–	–	0	0	0	3	2	1	3	1	1.5	1	4	S	50	NO	YES	1	A
T	3	–	8	4	–	–	–	–	–	–	17	5	8	12	28.7	0	0	H	40	–	–	2	A
T	3	–	8	4												1	1	H	40	–	–	2	AA
P-T[3]	3	–	8	5	–	–	–	–	–	13	15	6	16	22	38.0	0	0	H	40	–	–	2	B
P	13	48	8	5	–	–	–	1	–	9	16	12	10	16	23.0	0	0	H	40	–	–	2	C
RR-P[3]	12	66	8	5	–	–	–	–	–	13	10	2	16	10	20.0[6]	0	0	H	40	–	–	2	D
HH[3]	4	–	8	10	0/9	0/5	0/14	0/6	0/6	0/8	0/10	0/11	0/15	0/8	0/35.5	0	1	S	62	NO	YES-T.	3	A
RR	1	25	8	12	3/0	3/2	4/5	0/1	3/0	10/3	3/0	4/0	6/0	5/1	25/7.3	0	0	M	22	YES	NO	4	A
RR	1	16	8	11	4/0	8/0	5/0	1/0	3/0	5/0	2/0	4/0	5/0	6/0	14/0	0	0	M	22	YES	NO	4	B
RR	1	35	8	9	–	–	0/0	2/0	0/0	0/0	0/0	0/0	1/0	1/0	3.8/0	0	0	M	22	YES	NO	4	C
RR	1	16	17	9	–	0/0	7/1	0/0	0/0	6/0	1/0	1/0	7/0	4/0	14/0.5	0	0	M	22	YES	NO	4	D
RR	3	20	17	7	–	–	–	1	4	1	1	2	4	0	9.5	0	0	M	22	YES	NO	4	E
RR	1	5	8	1	–	–	–	–	–	–	–	–	–	4	22.5	0	0	M	22	YES	NO	4	F
RH	6	120	6	10	0/0	0/0	0/0	0/0	1/0	0/0	0/0	0/0	0/0	1/0	1.8/0	0	0	M	28	YES	NO	8	A
RR	6	180	12	9	0/0	2/0	1/0	0/0	0/0	0/1	0/0	0/0	1/1	0/0	3.6/1.8	0	0	M	28	YES	NO	8	B
RR	6	168	12	9	0/0	2/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/1	4.4/2.2	0	0	M	28	YES	NO	8	C
RR	6	174	6	9	–	0/0	0/0	0/1	0/0	0/0	0/0	0/0	0/1	0/0	0/1	0	0	M	28	YES	NO	8	D
RR	12	150	12	9	–	0/1	1/1	1/0	0/0	1/1	3/2	3/1	3/1	2/2	5.4/3.5	0	0	M	28	NO	YES-CP.	8	E
NO	18	120	18	26	0	0	1	2	0	4	3	2	4	1	7.2[6]	0	0	S	35	YES	YES-CP. & GR. RDS.	9	A
LH	3	42	13	11	1	3	4	6	5	1	1	5	3	2	3.9	0	0	H	40	YES	YES-REDUCE GR. RES.	13	A
LH	3	15	13	9	0	3	0	1	2	2	5	3	2	3	3.9	0	0	H	40	YES	YES-REDUCE GR. RES.	13	B
LH	3	29	13	12	1	0	0	0	1	0	2	1	1	2	3.0	0	0	M	40	YES	YES-REDUCE GR. RES.	13	C
LH	3	29	8	11												0	0	M	40	YES	YES-REDUCE GR. RES.	13	D
LH	3	29	8	11	–	–	–	–	–	3	0	1	1	9	6	7.1	0	0	M	40	YES	NO	13	DD
NO	1	60	8	10												3	4	M	40	YES	NO	14	A
LR	5	NO	16	14	2	1	0	1	0	2	0	0	0	0	1.9	0	0	S	42	YES	NO	15	A
NO	5	NO	16	11	0	0	1	0	0	0	0	0	0	0	0.35	0	0	S	42	YES	NO	15	B
RR[5]	2	NO	16	7	–	–	0	0	1	0	0	0	0	0	0.41	0	0	S	42	YES	NO	15	C
NO	5	NO	16	11	–	–	–	–	–	0	2	1	1	2	2.75	0	0	S	42	YES	NO	15	D
NO	5	NO	11	9	–	0	1	6	0	1	0	1	2	0	2.0	0	0	S	42	YES	NO	15	E
RR[5]	5	NO	11	8	–	0	2	1	2	0	1	1	0	1	7.3	0	0	S	42	YES	NO	15	F
NO	1	NO	16	13	0	1	1	0	0	0	0	1	0	0	1.0	0	0	H	42	YES	NO	15	G
NO	1	NO	16	10	0/0	0/0	0/1	1/0	0/0	1/0	1/0	1/0	1/0	1/0	1.5/0.3	0	0	H	42	YES	NO	15	H
NO	1	NO	16	13	0	0	0	0	0	0	0	1	0	1	0.9	0	0	H	42	YES	NO	15	I
HH	12	NO	9	9	–	–	–	–	6	23	33	15	13	23	24	0	2	–	33	–	NO	16	A
–	7	42	12	7	–	–	–	–	–	–	–	8	4	2	5.5	0	0	–	33	–	NO	16	B
LH	60	NO	12	14	6	7	7	?	7	3	3	2	3	?	9.5	0	0	H	35	NO	NO	17	A
LH	60	NO	12	12	1	2	2	0	0	0	2	1	3	0	4.0	0	0	H	35	NO	NO	17	B
FC	60	NO	12	13	2	6	2		0	0	1	0	1	0	5.8	0	0	H	35	NO	NO	17	C
LH-P	81	NO	12	7	–	–	–		0	0	2	1	0	1	2.0	0	0	H	35	YES	NO	17	D
P-T	31	NO	8	2	–	–	–		1	–	–	–	1	0	2.2	0	0	H	35	YES	NO	17	E
FC	27	NO	12	12	1	2	0	0	0	0	0	0	0	0	3.8	0	0	H	35	YES	NO	17	F
LH-P	60	NO	12	2	–	–	–	–	–	–	–	–	1	0	1.0	0	0	H	35	YES	NO	17	G
LH	60	NO	12	12	–	–	–	–	–	–	–	–	3	5	5.3	0	0	H	35	NO	NO	17	H
NO	–	–	–	12	1	3	0	0	2	1	1	0	0	0	13.8	0	0	M	38	YES	NO	18	A
NO	–	–	–	12	0/0	3/0	0/0	2/0	0/1	0/0	0/0	0/0	0/0	0/0	2.8/0.6	0	0	M	38	YES	NO	18	B
NO	–	–	–	10	0	1/0	1/0	0/0	0/0	0/0	0/0	0/0	1/0	0/0	1.7/0	1	1	M	38	YES	NO	18	C
NO	–	–	–	11	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/0	1/0	0/0	1.1/1.1	0	0	M	38	YES	NO	18	D
NO	–	–	–	10	0	1	0	0	1	0	1	0	1	0	4.4	0	0	M	38	YES	NO	18	E
NO	–	–	–	1	–	–	–	–	–	–	–	–	–	0/0	0/0	0	0	M	38	YES	NO	18	F
NO	–	–	–	12	1/1	1/0	0/0	0/0	0/1	0/0	0/0	0/0	0/2	1/0	3.0/4.0	1	1	M	38	YES	NO	18	G
NO	–	–	–	12	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/0	2/0	1/0	6.3/0	0	0	M	38	YES	NO	18	H
NO	–	–	–	14	1	1	0	0	3	0	0	0	0	0	8.2	0	0	M	38	YES	NO	18	I
NO	–	–	–	5	–	–	–	–	–	0/0	0/0	0/0	0/0	0/0	0/0	0	0	M	38	YES	NO	18	J
NO	–	–	–	5	–	–	–	–	–	0/0	0/0	0/0	0/0	0/0	0/0	0	0	M	38	YES	NO	18	K

TABLE II (CONTINUED) LIGHTNING PERFORMANCE AND

COMPANY	LINE	LINE CONSTRUCTION																LIGHTNING PROTECTION						
		K.V.	CIRCUITS	MILES (R.W.)	STEEL - WOOD	STRUCT. (FIG. N°)	CONDUCTOR HEIGHT AT TOWER MIN.-(FT.)			GR.W. HEIGHT (FT.) ABOVE TOP COND.	INSULATORS			CLEARANCE-LINE TO STRUCTURE (IN.) COND. SWING (DEG.)	CONDUCTOR ALUM.-COP.	ARMOR RODS	VIBRATION DAMPERS	AVG. SPAN (FT.)	GROUND WIRES	COUNTERPOISES		GROUND RODS		GR. RES. OF STRUCTURES		
											SPACING (INCHES)	NUMBER								FIG. N°	% OF LINE	PER TOW.	% OF LINE	AVG.		MAX
							TOP	MID.	BOT.			SUSP.	D.E.											BEFORE CP.-GR.	AFTER CP.-GR.	AFTER CP.-GR.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
18	L	132	2	53.2	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	695	1	NO	0	2-3	(d)	—	—	—
18	M	132	2	8.1	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	700	1	NO	0	2-3	(d)	—	—	—
18	N	132	2	67.8	S	1	76	63	50	11	5	10	12	48/38	C	NO	NO	685	1	NO	0	2-3	(d)	—	—	—
20	A	140	1	148.0	S	1-5	52	46	40	—	$4\frac{3}{4}$	10	12	48/20	C	NO	NO	520	0	NO	0	0	0	—	—	—
20	B	140	2	43.5	S	1	63	57	45	7.7	$4\frac{3}{4}$[V]	9	11-12	48/20	C	NO	NO	665	1	NO	0	0	0	—	—	—
20	C	140	1	44.3	S	1-5	52	46	40	6.7	$4\frac{3}{4}$	10	12	48/20	C	NO	NO	564	1	NO	0	1.6[q]	100	39	19.5	155
20	D	140	1/2	38.2[r]	S	1-6	48	48	48	6.7	$4\frac{3}{4}$[V]	10	11-12	48/20	A-C	NO	YES[w]	710	2-1	NO	0	1.0[q]	100	65-25	28-8.7	130-55
20	E	140	1	62.0	S	1	64	52	40	7	$4\frac{1}{4}$	10	12	48/20	C	NO	NO	517	1	NO	0	0	0	—	—	—
21	A	110	2	50.4	S	2	60	51	43	7	5	8	10	—	C	NO	NO	630	1	NO	0	0	0	—	—	—
21	B	132	2	189.0	S	1	85	74	63	12.4	5	8	10	—	A	YES	NO	1056	1	10-14	14	0	0	2.50	100	—
21	C	110	2	68.3	S	1	73	62	51	9	5	8	10	—	A-C	NO	NO	830	1	NO	0	0	0	—	—	—
21	D	110	1	68.3	W	8	36	32	28	4	5	7	9	—	A	NO	NO	330	1	NO	0	—	0	—	—	—
21	E	110	1	54.8	S	3	61	61	61	7	5	8	10	—	A	YES	NO	880	1	14	38	0	0	35	10	—
21	F	110	2	103.6	S	1	85	74	63	12.3	5	8	10	—	A	YES	NO	1056	1	NO	0	0	0	—	—	—
22	A	110	2	86.5	S	2	62	54	46	8.8	$5\frac{3}{8}$	7	8	35/45	A	NO	NO	530	2	NO	0	0	0	51	—	—
22	B	110	2	86.5	S	2	62	52	42	8.2	$4\frac{1}{4}$	7	8	33/45	A	NO	NO	530	1[q]	NO	0	0	0	51	—	—
22	C	165	2	135.2	S	2	74	62	50	9.5	$4\frac{3}{4}$	10	12	44/45	A	YES	NO	880	2	NO	0	0	0	175	—	—
23	A	132[t]	1	28.4	S	5	55	41	41	11.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	1410	1	NO	0	0	0	—	—	—
23	C	132[t]	2	56.9	S	1	83	70	57	11.9	$4\frac{3}{4}$	10	12	47/45	A	YES	NO	975	2	12	31	5	62	—	45.8[x]	—
23	D	132	1	30.7	S	1	85	70	57	10.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	1195	1	NO	0	0	0	60	—	—
23	G	132	2	65.0	S	1	83	70	57	10.9	$4\frac{3}{4}$[V]	10	12	47/45	A	NO	YES	1270	1	10-12	15	0	0	38.9	—	—
23	H	132	2	28.7	S	1	93	78	65	12.3	$5\frac{1}{8}$	11[n]	12	50/45	A	NO	YES	1175	1	NO	0	0	0	31.8	—	—
23	J	132	2	89.5	S	1	83	70	57	10.9	$4\frac{3}{4}$[V]	12[n]	12	50/45	A	YES	NO	1000	1	NO	0	0	0	2.2	—	—
23	K	132	2	63.2	S	1	83	70	57	10.9	$5\frac{1}{8}$[V]	10	12	50/45	A	YES	NO	1100	1	NO	0	0	0	2.5	—	—
23	L	132	2	18.1	S	1	76	63	50	12.9	$5\frac{1}{8}$	10	12	55/45	A	NO	YES	1620	1	NO	0	0	0	35.0	—	—
23	M	132	2	28.9	S	1	83	70	57	11.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	840	1	NO	0	0	0	—	—	—
23	N	132	2	80.6	S	1	83	70	57	11.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	930	1	NO	0	0	0	—	—	—
23	O	132	1	41.2	S	1	93	78	65	12.9	$5\frac{1}{4}$	9	11	50/45	A	YES	YES	1160	1	NO	0	0	0	—	—	—
23	P	132	2[r]	73.0	S	1	83	70	57	10.9	$4\frac{3}{4}$	11[n]	12	47/45	A	YES	NO	1320	1	NO	0	0	0	7.8	—	—
23	R	132	2	21.8	S	1	83	70	57	10.9	$4\frac{3}{4}$	11	12	50/45	A	YES	NO	1160	1	NO	0	0	0	5.5	—	—
23	S	132	2	80.6	S	1	83	70	57	11.9	$5\frac{1}{8}$	10	12	50/45	A	YES	NO	1065	1	NO	0	0	0	11.0	—	—
23	U	132	2	167.8	S	1	83	70	57	10.9	$4\frac{3}{4}$[V]	11	12	50/45	A	YES	YES	1240	1	NO	0	0	0	3.7	—	—
23	V	132	1	37.4	S	1	85	70	57	10.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	1200	1	NO	0	0	0	73.5	—	—
23	W	132	2	42.8	S	1	83	70	57	10.9	$4\frac{3}{4}$	12[n]	12	50/45	A	NO	YES	1130	1	NO	0	0	0	78.1	—	—
23	X	132	1	51.8	S	1	83	70	57	11.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	1180	1	NO	0	0	0	21.7	—	—
23	AA	132[k]	2	33.0	S	1	83	70	57	11.9	$5\frac{1}{8}$	10	12	50/45	A	YES	NO	1180	1	NO	0	0	0	—	—	—
23	BB	132	1	39.8	W	5	35	35	35	—	$5\frac{1}{4}$	10	12	—	A	NO	YES	955	0	NO	0	0	0	—	—	—
23	CC	132	2	47.9	S	1	85	70	57	12.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	1260	1	NO	0	0	0	—	—	—
23	DD	132	1	38.9	S	1	83	70	57	11.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	1170	1	NO	0	0	0	42.3	—	—
23	EE	132	2	23.6	S	1-3	83	70	57	12.8	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	1140	1	NO	0	0	0	—	—	—
23	FF	132	2	40.5	S	1-3	83	70	57	13.0	$4\frac{3}{4}$[v]	10	12	47/45	A	NO	YES	1270	1	NO	0	0	0	10.9	—	—
23	GG	132	1	47.9	S	1	84	70	57	12.5	—	—	—	—	A	NO	YES	—	1	NO	0	0	0	6.9	—	—
23	HH	132	2	38.0	S	1	83	70	57	11.9	$5\frac{1}{8}$	10	12	50/45	A	YES	NO	960	2	NO	0	5	52	24.5	—	—
23	II	132	1	63.4	S	1	83	70	57	10.9	$5\frac{1}{4}$	9	11	50/45	A	YES	YES	1150	1	NO	0	0	0	2.5	—	—
23	JJ	132	2	4.9	S	1	83	70	57	10.9	$5\frac{1}{4}$	9	11	50/45	A	YES	NO	1060	1	NO	0	0	0	—	—	—
23	KK	132	2	55.0	S	2	70	58	46	8.8	$4\frac{1}{4}$	10	12	42/48	C	—	—	595	2	NO	0	0	0	12.0	—	—
23	LL	132[k]	2	18.5	S	1	83	70	57	11.9	$5\frac{1}{8}$	10	12	50/45	A	NO	YES	640	1	NO	0	0	0	5.0	—	—
25	A	132	2	30.8	S	1	70	58	46	8.5	$4\frac{1}{4}$	12	13	42/60	A	YES	NO	814	1	NO	0	0	0	—	—	—
25	AA	132	2	27.6	S	2	68	53	42	12.3	$5\frac{1}{4}$	11	13	48/45	C	NO	NO	800	2	NO	0	0	0	—	—	—
25	B	132	2	113.6	S[w]	2	70	54	40	20.5	$5\frac{1}{4}$	11	13	66/45	C	NO	NO	830	2	NO	0	0	0	6.9	—	56
25	C	132	1	135.5	W	7	33	33	33	10.0	$5\frac{1}{4}$	11	13	42/45	A	YES	NO	524	2	NO	0	(x)	10	—	—	60
25	E	110[p]	2	143.6	S	1	70	60	50	8.3	$5\frac{1}{4}$	9	8	36/45	C	NO	NO	755	1	NO	0	0	0	—	—	—
26	A	132	4[h]	31.5	S	9	88	—	72	18.9	5	12	14	49/54	A	YES	NO	930	2	11-15	93	0	0	58	11.4	30
27	A	115	2	29.6	S	2	60	50	40	11.0	5	8	10	46/48	A	NO	NO	528	2	NO	0	0	0	—	—	—
28	A	130	2	54.7	S	5	72	59	46	10.3	$4\frac{1}{4}$	10	12	30/45	C	NO	NO	698	2	NO	0	0	0	—	—	—

FOR FOOT NOTES SEE END OF THIS TABLE.

CONSTRUCTION OF 110 KV. TO 165 KV. LINES

GRADING & ARC DEVICES[1]	FAULT CLEARING TIME (CYCLES) RELAYS PRIMARY (MIN.)	RELAYS BACK UP (MIN.)	OCB (MIN)	YEARS IN SERVICE	LINE OPERATION OUTAGES DUE TO LIGHTNING ONE CIRCUIT / TWO CIRCUIT 1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	AVG. OUTAGES/ 100 MILE OF LINE/YEAR	CASES OF BURNED DOWN CONDUCTORS	CASES OF PROLONGED OUTAGES	LIGHTNING[2] TERRITORY	ISOCERAUNIC LEVEL	OPERATING RECORD SATISFACTORY	CONSIDERING IMPROVEMENTS TO BETTER LINE PERFORMANCE	COMPANY	LINE
28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	1	2
NO	-	-	-	9	0/0	0/0	0/0	1/1	1/0	0/0	1/0	2/1	0/0	1/0	1.0/0.4	0	0	M	38	YES	NO	18	L
NO	-	-	-	7	-	-	0/0	0/0	0/0	0/0	2/0	0/0	0/0	0/0	3.1/0	0	0	M	38	YES	NO	18	M
NO	-	-	-	9	0/0	7/2	3/0	2/0	3/1	0/2	2/0	1/2	3/0	1/0	3.3/1.2	0	0	M	38	NO	YES-GR.RDS & C.P.	18	N
LH	12	NO	-	26	17	20	14	13	2	3	5	8	3	7	5.6	2	2	M	35	YES	YES-GR.RDS & GR.WR.	20	A
LH-PC	12	NO	-	13-8	3/0	4/0	1/0	1/3	0/0	0/0	0/0	0/0	0/0	1/0	2.3/0.7	0	0	M	35	YES	NO	20	B
LH	12	NO	-	18	16	14	17	23	6	10	13	7	6	4	26.2	1	1	M	35	YES	YES-C.P.	20	C
LH	3	NO	-	10	0	3	1	2	0	2	5	0	4	1	4.7	0	0	M	35	YES	YES-C.P.	20	D
LH	1	NO	-	20	1	2	5	4	4	21	8	3	14	24	15.8	2	3	M	35	NO	YES-C.P. & GR.RDS.	20	E
NO	3	3	18	23	2	0	0	2	1	2	0	1	1	0	1.8	0	0	L	25	YES	NO	21	A
NO	3	3	18	6	-	-	-	-	-	13	28	13/5	13/11	8/11	4.6/6.9	0	0	S	25	NO	YES-GR.W.-C.P. & T.	21	B
NO	3	3	20	8	-	1	5/0	0/1	0/0	2/4	3/4	0/0	2/1	3/5	2.8/2.4	0	0	H	25	YES	NO	21	C
NO	3	3	20	18	0	0	0	0	0	0	0	1	1	1	0.44	0	1	H	25	YES	NO	21	D
NO	3	3	20	4	-	-	-	-	-	-	-	6	7	3	9.8	0	1	L	25	NO	YES	21	E
NO	3	3	18	9	-	-	1/1	1/0	2/1	5/1	2/0	2/1	1/2	4/0	2.2/0.7	0	0	M	25	NO	YES	21	F
LH	6	120	8	27	1/0	6/1	0/4	3/3	2/3	3/5	0/2	4/5	0/0	1/2	2.3/2.9	NIL	3	M	25	NO	YES-C.P. INST. 1938	22	A
LH	6	120	8	17	4/3	13/7	10/6	8/4	4/4	16/3	4/3	6/5	4/1	4/3	8.7/4.5	NIL	2	M	25	NO	YES-C.P. INST. 1938	22	B
LH	2	38	14	11	3/0	6/0	10/3	13/4	0/5	3/8	12/10	1/3	1/3	3/4	3.8/3.0	NIL	1	M	25	NO	YES-C.P. INST. 1938	22	C
NO	1	69	22	8	-	-	3	8	0	3	5	5	7	0	13.2	0	0	S	56	YES	NO	23	A
RR	1	29	22	9	-	-	4/4	4/2	3/5	2/2	2/3	3/13	5/4	0/5	4.5/8.0	0	0	M	27	YES	NO	23	C
RR-T[4]	1	29	8	11	6.3	10.1	14.5	11.3	3.8	8.1	2	1	1	0	18.8	0	0	S	55	YES	NO-T NOW INST.	23	D
RH-T[4a]	3.5	20	8	11	5/2	19/11	7/4	15/15	4/2	5/2	15/11	5/2	32/8	10/0	18.0/7.3	0	0	S	53	YES	NO-T & C.P NOW INST.	23	G
RH	1	29	8	11	1/1	6/3	2/3	6/2	0/0	3/4	3/3	1/3	3/4	4/0	10/8	0	0	S	54	YES	NO	23	H
RR	1	35	8	5	-	-	-	-	-	4/1	9/0	3/0	5/1	6/4	6/1.3	0	0	H	43	YES	NO	23	J
RH	1	41	8	9	-	0	3	16	3	5/1	5/1	5/1	6/0	4/3	8.3/1.9	0	0	H	44	YES	NO	23	K
NO	1	35	8	4	-	-	-	-	-	-	3/6	1/1	3/1	4/4	13.8/16.5	0	0	S	54	YES	NO	23	L
RR	1	46	8	9	-	1/0	2/0	0/0	0/1	0/0	2/0	1/0	3/1	3/0	4.6/0.8	0	0	H	45	YES	NO	23	M
RR	1	29	8	9	-	5/1	6/3	2/0	3/1	9/1	4/0	4/2	3/0	11/0	6.3/1.1	0	0	H	46	YES	NO-FB NOW INST.	23	N
RH	1	41	8	10	7	9	1	6	5	11	0	6	-	-	13.6	0	0	H	41	NO	YES-GR-CP INST. 1938	23	O
RH-T[4]	1	41	8	13	10/2	9/2	1/3	3/5	3/2	2/4	16/8	14/3	6/0	12/1	10.4/5.0	0	0	S	45	YES	NO	23	P
RR-RH	1	18	8	13	2	1	0/0	0/1	0/2	1/1	0/4	2/0	5/3	2/0	6.0/6.3	0	0	S	46	YES	NO	23	R
RR	1	24	8	8	-	3	3	5	3	9	5/3	7/2	8/2	11/6	7.8/3.3	0	0	H	45	NO	YES-GR-CP-T-FB.	23	S
RR	1	29	8	12	5/7	24/3	11/1	19/4	8/5	10/4	13/3	10/6	11/4	11/7	7.7/2.6	0	0	S	50	YES	NO	23	U
RR-T[4]	1	41	8	11	7.6	12.1	17.5	13.7	4.5	9.7	1	3	7	12	23.4	0	0	S	55	NO	YES-T REVAMP.	23	V
RH	1	29	8	12	6/4	11/5	8/3	15/11	4/6	3/2	7/0	6/2	23/20	10/13	21.7/18.0	0	0	S	54	NO	YES-GR-CP.-FB.	23	W
RH	1	41	8	10	5	13	7	9	7	6	13	2	19	4	16.4	0	0	S	56	YES	NO	23	X
RR	1	24	22	7	-	-	-	4/5	2/2	4/3	2/1	1/1	8/0	2/4	9.4/6.6	0	0	S	51	YES	NO	23	AA
NO	1	18	8	8	-	-	11	17	7	7	19	17	21	20	37.2	0	0	S	54	NO	YES-GR-C.P.	23	BB
RH	1	41	8	10	16/2	11/0	7/1	10/7	8/8	6/7	3/5	6/6	13/7	9/7	10.6/13.2	0	0	S	54	NO	NO	23	CC
RH	1	24	8	10	5	16	9	21	16	9	6	16	22	5	32.2	0	0	S	55	NO	YES-GR.-CP-FB.	23	DD
RR	1	41	8	9	-	4/3	1/2	3/1	1/1	1/3	3/1	5/4	11/8	0/1	13.6/11.2	0	0	S	53	YES	NO	23	EE
RH	1	41	8	12	12/1	11/4	4/1	5/5	2/0	11/3	8/5	0/2	11/2	1/3	16.0/6.4	0	0	S	54	YES	NO	23	FF
T	1	29	8	2	-	-	-	-	-	-	-	2	1	0	2.1	0	0	S	52	YES	NO	23	GG
RR	1	35	8	8	-	-	3/0	0/4	2/2	5/4	6/5	6/1	3/3	4/2	9.5/6.9	0	0	H	40	YES	NO	23	HH
RH	1	24	8	9	-	7	3	10	7	6	8	3	4	7	9.3	0	0	H	42	NO	YES-2 CIRC. 1938	23	II
RH	10	35	8	13	0/0	1/2	1/0	0/0	2/1	0/0	0/0	2/0	0/1	1/0	14.3/8.2	0	0	H	41	YES	NO	23	JJ
HH	1	29	22	22	2/0	2/0	0/0	0/2	1/0	1/0	0/1	1/0	1/1	0/0	1.5/0.7	0	0	M	45	YES	NO	23	KK
RR	1	18	22	8	-	-	3/0	1/0	0/0	1/0	0/1	1/0	3/1	1/1	6.8/2.0	0	0	H	45	YES	NO	23	LL
RR	INST.	102	8	13	-	-	-	1/1	3/1	0/1	7/0	8/2	1/0	6/0	6.4/1.2	0	0	S	55	YES	NO	25	A
RR	INST.	90	8	8	-	-	-	-	-	-	-	-	-	-		0	0	S	55	YES	NO	25	M
NO	INST.	24	8	7	-	-	-	0/0	0/0	1/0	0/0	0/0	0/0	0/0	0.12/0	0	0	S	55	YES	NO	25	B
NO	INST.	24	8	7	-	-	-	0	0	1	1	0	0	0	0.21	0	0	S	55	YES	NO	25	C
HH	18	NO	-	26	6/0	2/0	0/0	2/1	6/0	0/0	5/0	2/0	2/0	1/0	1.8/0.07	1	1	S	55	YES	NO	25	E
NO	12	90	8	3	-	-	-	-	-	-	-	0	0	0	1	0	1	H	35	YES	NO	26	A
LH	18	51	12	8	-	-	0/0	1/1	0/1	2/2	1/0	1/0	0/0	1/0	2.1/1.7	0	0	H	45	YES	NO	27	A
LH[3]	28	INST.	12	24	0/1	0/0	0/1	0/0	0/0	1/0	0/0	0/0	1/0	1/1	0.6/0.6	1	1	M	35	YES	NO	29	A

COMPANY	LINE	LINE CONSTRUCTION: K.V.	CIRCUITS	MILES (R.W.)	STEEL - WOOD	STRUCT. (FIG. N°)	CONDUCTOR HEIGHT AT TOWER MIN.-(FT.) TOP	MID.	BOT.	GR. W. HEIGHT (FT.) ABOVE TOP COND.	INSULATORS: SPACING (INCHES)	NUMBER: SUSP.	D.E.	CLEARANCE-LINE TO STRUCTURE (L/L) COND. SWING (DEG.)	CONDUCTOR ALUM. - COP.	ARMOR RODS	VIBRATION DAMPERS	AVG. SPAN (FT.)	LIGHTNING PROTECTION: GROUND WIRES	COUNTERPOISES: FIG. N°	% OF LINE	GROUND RODS: PER TOWER	% OF LINE	GR. RES. OF STRUCTURES AVG.: BEFORE CP.-GR.	AVG.: AFTER CP.-GR.	MAX: AFTER CP.-GR.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
29	B	130	2	79.5	S	5	72	59	46	10.3	4 3/4	10	12	30/45	C	NO	NO	633	2	NO	0	NO	0	—	—	—
29	C	130	1	34.6	W	7	41	41	41	6.3	4 3/4	10	12	35/45	C	NO	NO	546	2	NO	0	1	100	—	—	—
29	D	130	1	79.8	W	7	41	41	41	6.3	4 3/4	10	12	35/45	C	NO	NO	513	2	NO	0	1	100	—	—	—
29	E	130	1	82.1	W	7	41	41	41	7.3	5 1/8	10	12	41/45	C	NO	NO	612	2	NO	0	1	100	—	—	—
29	F	130	1	9.6	W	7	41	41	41	6.3	4 3/4	10	12	35/45	C	NO	NO	475	2	NO	0	1	100	—	—	—
30	A	110	2	21.0	S	2	58	49	41	5.6	5 3/4	7	9	42/45	C	NO	NO	483	1	NO	0	NO	0	—	—	—
30	B	110	2	21.0	S	1-2	58	49	41	7	5 3/4	7	9	42/45	C-A	NO	NO	476	1-2	NO	0	NO	0	—	—	—
30	C	110	2	36.0	S	2	58	49	41	7	5 3/4	7	9	42/45	A	NO	NO	508	2	NO	0	NO	0	—	—	—
30	D	110	2	109.0	S	2	58	49	41	7	5 3/4	7	9	42/45	A	NO	NO	558	2	NO	0	NO	0	—	—	—
30	E	110	2	71.5	S	1-2	58	49	41	7	5 3/4	7	9	42/45	A	NO	NO	485	1	NO	0	NO	0	—	—	—
31	A	132	1	80.9	W	7	40	40	40	8.1	5 3/4	10	12	76/45	C	—	NO	588	2	NO	0	NO	0	—	—	—
31	B	132	1	111.0	W	7	42	42	42	—	5 3/4	9	11	79/45	A	YES	NO	587	0	NO	0	1	100	—	—	—
32	A	120	2	38.1	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	800	1	NO	0	1	100	—	—	—
32	B	120	2	55.5	S	1	84	72	60	8.5	5	9	10	42/45	C	NO	NO	720	1	NO	0	NO	0	—	—	—
32	C	120	2	18.1	S	1	84	72	60	8.5	5	9	10	42/45	C	NO	NO	700	1	NO	0	NO	0	—	—	—
32	D	120	2	13.3	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	740	1	NO	0	NO	0	—	—	—
32	E	120	2	35.5	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	730	1	NO	0	NO	0	—	—	—
32	F	120	2	25.8	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	740	1	NO	0	NO	0	—	—	—
32	G	120	2	16.1	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	740	1	NO	0	NO	0	—	—	—
32	H	120	2	3.6	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	600	1	NO	0	NO	0	—	—	—
32	I	120	2	15.2	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	630	1	NO	0	NO	0	—	—	—
32	J	120	2	14.5	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	680	1	NO	0	NO	0	—	—	—
32	K	120	2	20.7	S	1	81	71	61	8	5	9	10	42/45	C	NO	NO	530	1	NO	0	NO	0	—	—	—
32	L	120	2	17.7	S	1	77	66	55	8	5	9	10	42/45	C	NO	NO	470	1	NO	0	NO	0	—	—	—
34	A	110	1	71.6	W	7	44	44	44	8	5 3/4	7	12	—	C	NO	NO	692	2	NO	0	1	100	—	—	—
34	B	110	1	84.1	W	7	48	48	48	9.5	6 7/16	8	12	—	A	YES[Y]	NO	902	2	NO	0	1	100	—	—	—
34	C	154	1	83.5	W	7	34	34	34	8.5	5 3/4	10	12	—	C	NO	NO	453	2	NO	0	1	100	—	—	—
34	D	110	2	48.6	S	2	63	53	43	7	5 1/8	7	8	—	C	NO	NO	645	2	NO	0	NO	0	—	—	—
34	E	110	1	125.5	S	3	56	56	56	12	5 1/2	10	11	—	A	YES[Y]	YES[Y]	970	2	NO	0	NO	0	—	—	—
34	F	110	1	97.4	W	7	49	49	49	8	5 3/4	7	12	—	A	YES	NO	828	2[Z]	NO	0	1	100	—	—	—
34	G	110	1	38.6	W	7	36	36	36	7.9	5 1/8	7	8	—	A	NO	NO	713	2	NO	0	1	100	—	—	—
34	H	110	1	130.0	W	7	52	52	52	8.3	5 3/4	8	9	—	A	YES[Y]	NO	836	2	NO	0	1	100	—	—	—
34	I	110	1	58.8	W	7	45	45	45	6.5	6 7/16	8	11	47/30	A	YES	NO	910	2	NO	0	1	100	—	—	—
34	K	110	1	38.3	S	1	66	56	46	8	4 3/4	7	9	56/30	C	NO	NO	679	0	NO	0	NO	0	—	—	—
34	L	110	2	87.8	S	2	60	51	42	7.3	4 3/4	8	12	35/30	C	NO	NO	615	2	NO	0	NO	0	—	—	—
34	M	110	2	55.9	S	1	66	56	46	8.1	4 3/4	7	9	47/30	C	NO	NO	663	1	NO	0	NO	0	—	—	—
34	N	110	2	21.2	S	2	74	60	46	12.6	5	9	10	67/30	A	YES	NO	939	2	NO	0	NO	0	—	—	—
34	O	110	1	104.5	S	3	44	44	44	5.5	4 3/4	11	12	42/30	C	NO	NO	603	0	NO	0	NO	0	—	—	—
35	A	132	2	73.9	S	1	71	60	49	9.3	4 3/4	9	11	36/45	C	NO	NO	810	1	NO	0	NO	0	—	—	—
35	B	132	1	83.7	S	2	81	68	55	12.9	4 3/4	9	11	38/45	A	NO	NO	940	1	NO	0	NO	0	—	—	—

FOOT NOTES TO TABLE II

(1) RR-RING AND RING; RH-RING AND HORN; LH-LINE HORN ONLY; HH-HORN AND HORN; P-THOMAS SPOONS; T-PROTECTOR TUBES; LR-LINE RING ONLY; FC-FLUX CONTROLS; FB-FAST RECLOSING, HIGH SPEED O.C.B.

(2) S-SEVERE; H-HEAVY; M-MEDIUM; L-LIGHT.

(3) ONE CIRCUIT ONLY.

(4) TWO SINGLE CIRCUIT LINES ON ONE RIGHT OF WAY.

(5) OUTSIDE CONDUCTORS ONLY - CENTER CONDUCTOR 8 UNITS.

(6) TWO PER CIRCUIT.

(7) DEAD ENDS ONLY.

(8) LINES 15A AND 15B ON SAME TOWERS (279 TOWERS) 15A ALONE ON 37 TOWERS.

(a) ONE GROUND WIRE PER CIRCUIT.

(b) TOP CONDUCTOR ONLY.

(c) 15D AND 15E ON SAME TOWERS FOR 198 TOWERS.

(d) 2 TO 3 GROUND RODS AT TOWERS WITH CONCRETE ANCHORS ONLY.

(e) GROUND RODS INSTALLED APRIL 1937.

(f) LINE IN TWO SECTIONS - 1 CIRCUIT 29 MILES / 2 CIRCUIT 9.2 MILES.

(g) ON COUNTERPOISE SECTION ONLY.

(h) 25 CYCLE SINGLE PHASE.

(i) BUILT FOR 132 KV. - OPERATED AT 44 KV.

(j) BUILT FOR 132 KV. - OPERATED AT 66 KV.

CONSTRUCTION OF 110 KV. TO 165 KV. LINES

GRADING & ARC DEVICES[1]	FAULT CLEARING TIME (CYCLES) RELAYS PRIMARY (MIN.)	RELAYS BACK UP (MIN.)	OCB (MIN.)	LINE OPERATION: YEARS IN SERVICE	OUTAGES DUE TO LIGHTNING ONE CIRCUIT / TWO CIRCUIT 1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	AVG. OUTAGES/100 MILE OF LINE/YEAR	CASES OF: BURNED DOWN CONDUCTORS	CASES OF: PROLONGED OUTAGES	LIGHTNING TERRITORY[2]	ISOCERAUNIC LEVEL	OPERATING RECORD SATISFACTORY	CONSIDERING IMPROVEMENTS TO BETTER LINE PERFORMANCE	COMPANY	LINE
28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	1	2
LH[3]	36	INST	14	24	0/0	0/0	1/1	0/1	0/0	1/0	0/0	0/0	0/0	1/1	0.4/0.4	0	0	M	35	YES	NO	29	B
NO	23	INST	13	20	0	0	0	0	0	0	0	0	0	0	0	0	0	M	35	YES	NO	29	C
NO	34	INST	22	20	1	0	0	1	0	0	0	0	1	1	0.5	0	0	M	35	YES	NO	29	D
NO	30	NO	10	11	0	0	1	0	0	0	0	0	3	0	0.5	1	1	M	35	YES	NO	29	E
NO	41	NO	14	14	0	0	0	0	0	0	0	0	0	0	0	0	0	M	35	YES	NO	29	F
NO	1	—	8	16	—	—	—	—	—	9/0	0/0	1/0	2/0	0/0	11.4/0	0	0	M	30	YES	NO	30	A
NO	1	—	8	8	—	—	—	—	—	1/0	0/0	0/0	1/0	0/0	1.8/0	0	0	M	30	YES	NO	30	B
NO	1	—	8	15	—	—	—	—	—	0/0	1/1	0/1	0/0	0/0	0.4/0.7	0	0	M	30	YES	NO	30	C
NO	1	—	20	12	—	—	—	—	—	7/5	7/1	6/1	0/2	11/3	5.7/2.2	0	0	M	30	NO	NO	30	D
NO	1	—	20	7	—	—	—	—	—	8/0	2/1	2/3	1/0	3/1	4.5/1.4	0	0	M	30	YES	NO	30	F
NO	20	INST	7	11	—	—	—	—	—	—	—	—	—	1	1.2	0	0	L	25	YES	NO	31	A
NO	INST	45	3	17	—	—	—	—	—	—	—	—	—	0	0	0	0	L	25	YES	NO	31	B
NO	2	17	5	14	8/0	5/2	1/0	2/0	1/1	2/0	1/0	0/0	0/1	5/3	6.6/1.1	0	2	H	35	YES	NO	32	A
LH	2	15	5	10	2	1	3/0	3/0	2/0	7/0	4/0	1/0	2/0	3/1	5.6/0.2	1	1	H	35	YES	NO	32	B
LH	2	26	5	11	1/0	1/0	0/0	0/0	0/0	1/0	0/0	0/0	4/0	2/0	5.0/0	0	0	H	35	YES	NO	32	C
LH	2	32	5	14	7/0	3/0	1/0	1/0	1/0	0/0	0/0	0/0	0/0	2/0	11.3/0	0	0	H	35	YES	NO	32	D
LH	2	36	5	14	9/0	1/0	1/0	3/1	4/1	1/0	2/0	2/0	1/0	4/1	7.9/0.8	0	0	H	35	YES	NO	32	E
LH	2	33	5	13	2/0	2/1	1/0	1/0	2/1	1/0	2/0	0/0	2/0	0/1	5.0/1.2	1	1	H	35	YES	NO	32	F
LH	2	19	5	13	1/1	0/0	1/0	2/0	3/1	1/0	2/0	0/0	1/0	7/1	11.2/1.9	1	1	H	35	YES	NO	32	G
LH	2	22	5	14	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	H	35	YES	NO	32	H
LH	2	24	5	14	2/0	0/0	0/0	1/0	0/0	1/0	0/0	1/0	4/0	0/0	5.9/0	1	2	H	35	YES	NO	32	I
LH	2	24	5	12	2/0	0/0	0/0	2/0	0/0	0/0	0/0	1/0	0/0	0/1	3.5/0.7	1	3	H	35	YES	NO	32	J
LH	2	27	5	12	2/0	2/0	1/0	0/0	0/0	1/0	0/0	2/0	4/0	3/1	7.3/0	2	2	H	35	YES	NO	32	K
LH	2	27	5	10	0/0	1/0	0/0	2/0	0/0	1/0	0/0	2/0	0/0	1/0	4.0/0	0	0	H	35	YES	NO	32	L
LH	1	75	8	13	22	6	2	4	5	3	8	0	11	3	9.0	0	2	M	68	YES	NO	34	A
RR[4]	1	70	8	9	—	5	1	2	1	1	1	1	1	6	2.5	0	0	H	68	YES	NO	34	B
LH	1	60	8	11	10	6	7	4	7	9	6	7	12	7	8.4	3	10	H	68	YES	NO	34	C
LH	1	50	8	24	17/11	9/4	6/6	3/11	7/2	1/4	11/30	2/7	4/13	7/9	13.8/20	18	31	H	68	NO	YES	34	D
RR	1	60	8	10	37	14	7	17	18	19	23	15	38	17	15.9	0	5	S	68	YES	NO	34	E
LH	1	60	8	11	23	10	19	23	24	18	31	15	39	21	23.0	7	14	S	68	YES	NO	34	F
LH	1	50	8	15	11	7	9	8	5	7	15	7	14	7	23.4	2	5	H	68	YES	NO	34	G
LH	1	15	8	12	23	17	8	17	13	8	14	11	7	12	10.0	0	4	S	68	YES	NO	34	H
NO	20	NO	18	9	—	—	6	2	0	2	3	0	5	6	4.9	0	0	H	65	YES	NO	34	I
NO	INST	NO	18	14	34	19	18	25	25	12	18	15	42	25	61.0	0	0	H	65	NO	NO	34	K
NO	10	60	18	25	7/6	6/1	10/2	4/7	6/3	4/4	10/6	3/4	27/8	4/1	9.2/4.4	7	1	M	65	YES	NO	34	L
NO	INST	50	18	14	21/7	28/5	11/23	6/11	4/17	12/12	18/21	5/5	20/31	7/13	25.7/26.0	13	6	S	65	NO	NO	34	M
(s)	15	60	12	8	—	—	—	4/0	4/1	5/1	5/3	5/1	11/1	7/1	27.7/3.4	3	1	M	65	YES	NO	34	N
NO	INST	90	8	13	56	24	27	37	29	13	46	16	50	41	22.8	0	4	S	65	NO	NO	34	O
LH	3	NO	5	13	—	—	4/2	2/4	4/3	6/2	7/1	3/1	1/4	2/3	4.9/3.4	1	2	H	45	—	YES-GR. RDS.	35	A
NO	5	NO	5	10	—	—	2	2	2	4	6	2	2	4	0.9	0	0	H	45	—	YES-GR. RDS-C.R.	35	B

(k) AFTER INSTALLING GROUND RODS BUT BEFORE COUNTERPOISES.
(l) PROTECTOR TUBES INSTALLED SPRING OF 1934 AND RING AND RINGS REMOVED.
(m) PROTECTOR TUBES INSTALLED ON ONE CIRCUIT SUMMER OF 1933 - RINGS AND HORNS REMOVED FROM THIS CIRCUIT.
(n) TOP AND MIDDLE PHASES ONLY; BOTTOM PHASE 10 UNITS.
(o) SINGLE AND DOUBLE CIRCUIT OUTAGES NOT SEGREGATED.
(p) 25 CYCLE LINE.
(q) BUILT FOR 132 KV., OPERATED AT 33 KV.
(r) ONE CIRCUIT WITH PROTECTOR TUBES - AND SECTIONALIZED AT MID-POINT - PROTECTOR TUBES INSTALLED SEPTEMBER 1933.
(s) PROTECTOR TUBES EVERY FIFTH TOWER.
(t) RINGS AND RINGS ONE CIRCUIT - SPOONS ON OTHER CIRCUIT.
(u) LINE 2AA AND CONTINUING 2A LINE INCLUDED TOGETHER AS 38.8 MILES.
(v) SOME LONGER SPACED UNITS IN USE.
(w) WOOD ARMS.
(x) AS REQUIRED TO REDUCE RESISTANCE TO 60 OHMS OR LESS.
(Y) ON PART OF LINE ONLY.
(z) GROUND WIRES ON 67.3 MILES ONLY.

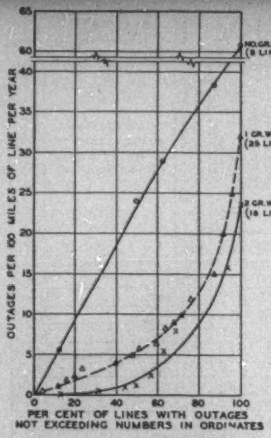

NO GR. WIRES (8 LINES)
1 GR. WIRE (25 LINES)
2 GR. WIRES (16 LINES)
OUTAGES PER 100 MILES OF LINE PER YEAR
PER CENT OF LINES WITH OUTAGES NOT EXCEEDING NUMBERS IN ORDINATES

Figure 16. Effect of ground wires on lightning outages of single-circuit lines

of outages (from table III) is 1.40. While these figures are indicative of the benefit accruing from using a second ground wire it should be kept in mind that many of the two-ground-wire lines have been constructed with more insulation and other lightning resistant features than have generally been employed on some of the older single-circuit lines.

A clearer graphic picture of the benefits of the use of ground wires is shown in figure 16. On all single-circuit lines with and without ground wires, where the record is clear, it is shown that 50 per cent of the lines included here have outages not exceeding 24 for 100 miles with no ground wire, 5.5 with one ground wire, and 2.0 with two ground wires.

Considerable theory and discussions have been presented in the past on the desirability of locating the ground wire at a considerable height above the line conductors. In an attempt to obtain statistical data on this subject, the average line outages for 10 years, or the period reported, have been plotted against the height of ground wire above the top conductor. The record is shown in figure 17. While it appears that two lines, one with a ground wire 18.9 feet and the other 20 feet above the line conductor, have a practically perfect operating record, it should be pointed out, however, that both of these lines also have line insulation and clearance at the tower considerably higher than has been generally reported for other lines of the same voltage classification. With outages ranging from 0 to 61.0 per year where the ground wire heights range from 7 to 13 feet above the conductor, however, it would appear that there are other factors more important than the height of the ground wire above the conductor that control the outages.

Single-Circuit and Two-Circuit Outages

A comparison of single- and double-circuit outages is given in figure 18. It will be noted that for 50 per cent of the two-circuit lines the double-circuit outages do not exceed about 1.0 and the single-circuit outages 4.0 per 100 miles of line per year. It thus appears that the double-circuit outages are 20 per cent of the total outages on two-circuit lines for 50 per cent of the cases. For 80 per cent of the lines, 32 per cent of the outages are double circuit. As the yearly outages increase, single- and double-circuit outages become nearly equal.

A comparison of single-circuit steel and wood lines is also shown graphically in this figure 18. Here wood does not show up to any particular advantage against steel.

Tower Footing Resistance

The beneficial effect of tower footing resistance in reducing lightning outages has been presented both theoretically and from practical operating data previously. To throw some further light on this aspect of lightning protection, the pertinent data have been taken from table II and plotted against average tower footing resistance in figure 19. The trend to low outages with low resistance is quite marked here. The general conclusion that can be drawn from this curve is that if the line outages are to be kept to a low value, the tower footing resistance should be not in excess of 10 ohms per tower. It should be noted, however, that low tower footing resistance, or counterpoises, alone will not suffice, as shown by a few yearly outages from 5 to 22 even where the resistance is 10 ohms or less per tower.

Local Lightning Severity

Any accurate comparison of the lightning performance of lines must of necessity take into account the lightning conditions under which the line is called upon to operate. An attempt to reduce lightning outages to a common basis would require a reasonably accurate evaluation of the lightning severity in the territory where the line is located. No easy way of doing this presents itself. However, columns 46 and 47 of table II indicate to some degree the severity of the lightning territory. The data in column 46 is the estimate of lightning severity given by the reporting companies. The figure in column 47 is the isokeraunic level taken from the 20-year average isokeraunic data as published by the United States Government. The lightning territory in this tabulation ranges from lightning storms of a density of 22 storms per year up to a maximum of 68 per year, that is, a ratio of over three to one. No attempt has been made to evaluate line outages taking into account this variation of lightning density as it is felt that the data as a

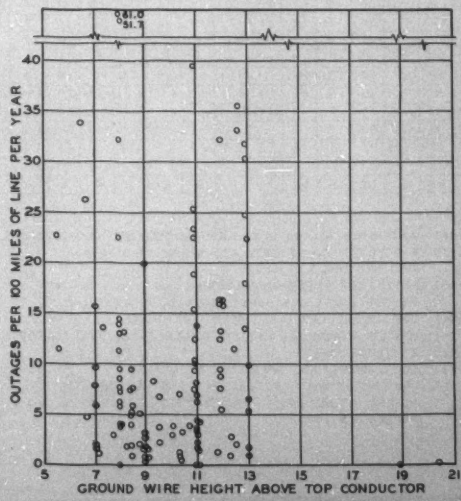


Figure 17. Effect of ground wire height on line outages. Steel-tower lines only

whole do not lend themselves readily to this type of analysis. The conclusions drawn from such an analysis might be so susceptible to error that no quantitative correlation has been attempted. In general, however, it is quite noticeable that the higher figures for line outages per year are associated, as might be expected, with the higher lightning density of the territory where the line is located.

Insulators and Line Clearance

All insulators are, of course, of the suspension type and range in size from 4¾-inch spacing to 6½-inch. The number of insulators used in suspension strings ranges from 6 to 8 for wood structures and from 6 to 11 for steel structures in the 110-kv class to 9 to 11 for wood and 8 to 12 in the 132-kv class. This is exclusive of the long spaced (6½-inch) unit, used on a few lines.

Where wood structures are used, it will be noted that there is no general tendency to decrease the number of insulators used. However, in some of the 110-kv wood-pole lines seven units are used, although there is little apparent indication that this number of units was used with the intention of utilizing the wood as normal-frequency voltage insulation.

In the matter of clearances at towers between the conductor and the tower structure, it will be noted that the clearance ranges from a minimum of 31 inches for 110-kv lines up to a maximum of 67 inches at 45 degrees and 30 degrees conductor swing, respectively. For the 132-kv lines the range of clearances is from 37 inches to 66 inches at conductor swings in the order of 50 degrees.

In general it is not apparent from an analysis of the line outage data that the amount of insulation provided in the insulator string itself has a great deal of bearing on the performance of the line under lightning conditions. In other words, any attempt to overinsulate a line beyond normal requirements does not appear to have much influence on its lightning outage record.

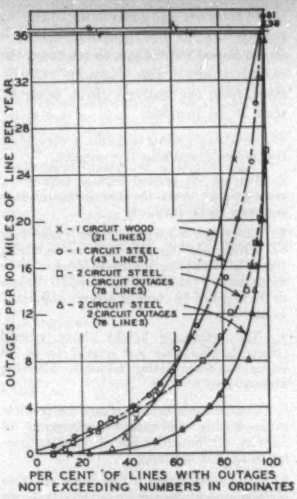

OUTAGES PER 100 MILES OF LINE PER YEAR
PER CENT OF LINES WITH OUTAGES NOT EXCEEDING NUMBERS IN ORDINATES
X - 1 CIRCUIT WOOD (21 LINES)
O - 1 CIRCUIT STEEL (43 LINES)
□ - 2 CIRCUIT STEEL 1 CIRCUIT OUTAGES (78 LINES)
Δ - 2 CIRCUIT STEEL 2 CIRCUIT OUTAGES (78 LINES)

Figure 18. Lightning outages on transmission lines. Single- and double-circuit lines with wood or steel structures

Heights of Conductors

The opinion has sometimes been expressed in the past that a line which was built low to the ground was more immune from lightning troubles. The data presented in table II, however, fail to bear out this contention. For example, a comparison of the operating record of the lines of company 4, where the height of conductors is 46 feet, with the record of company 8, where the height of conductors is 100 feet, shows on an average higher outages for the line built closer to the ground. A comparison of other lines given in the table gives the same type of conflicting data. From this record it might be concluded that whatever factor the height of the line above ground may have in influencing the lightning outages, it is frequently submerged in other factors of line construction.

Arcing Protection and Prolonged Outages

In an attempt to determine whether high-voltage transmission systems in general are subject to prolonged outages, the data in columns 44 and 45 of table II have been listed. Analysis of these data shows that in general burned-down conductors and prolonged outages, except in the case of one company, are relatively rare and are confined almost entirely to those circuits where the most modern type of arcing protection is absent. Most of the cases reported are on lines having insulator strings equipped with arcing horns on the line side only, or where no arcing protection at all is applied to the insulator strings. A summary of the record shows the following:

	Rings and Horns or Rings and Rings	Line Rings Only	No Protection
Burned-down conductors	1	44	31
Prolonged outages	9	85	27
Miles of line	1,962	2,022	2,613

A study of the relay and breaker times to clear faults (columns 29, 30, and 31 of table II) does not clearly indicate that moderately fast clearing of the fault will mitigate line troubles unless some effective arcing protection is applied to the insulator assemblies. It should be pointed out, however, that the relay and breaker operating times in table II are those presumably in use at the present time, so that troubles reported in many cases may have occurred before means were taken to speed up relay and breaker time.

Satisfactory Performance of Lines and Improvements Considered

In answer to the question as to whether the lightning outage performance of the lines as given by each company was satisfactory or not and whether improvements were being considered to better that performance, it will be noted from columns

Table III. Effect of Ground Wires on Lightning Outages of 165–110 Kv Transmission Lines

	Number of Lines	Line Miles	Outages per 100 Miles of Line per Year
No-ground-wire lines			
Single-circuit wood	5	250.9	30.2
Single-circuit steel	3	290.8	29.8
Total		541.7	30.0
One-ground-wire lines			
Single-circuit wood	1	68.3	0.44
Single-circuit steel	27	1,086.1	9.8
Double-circuit wood			
Double-circuit steel	51	2,236.3	7.1/4.2
Two-ground-wire lines			
Single-circuit wood	12	940.0	5.1
Single-circuit steel	4	241.9	7.0
Double-circuit wood			
Double-circuit steel	18	969.9	5.2/3.5

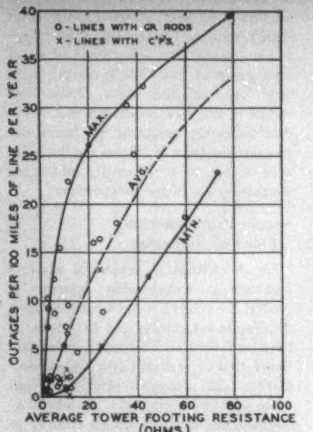


Figure 19. Effect of tower footing resistance on line outages for steel-tower ground-wire lines

48 and 49 in table II that in the large majority of cases, companies reported the operation was considered satisfactory. It should be pointed out, however, as mentioned by one reporting company, that while the outage record of some lines is not considered particularly low, the particular operating conditions do not require the high grade of line performance which might be required under some other operating conditions. For example, where two-circuit lines are in use, a high single-circuit outage record is not highly objectionable. On the other hand, where the outage record is high for double-circuit outages, or for single-circuit outages on single-circuit lines, the condition is entirely different. Again, where lines are operated in parallel with other lines between the source of power and load, or serve as a tie between two sources of power, the outage performance of such lines under lightning conditions may not be as exacting as in the case of lines which are the only source of power supply to important loads.

It will be noted that the general types of improvement being considered comprise lowering tower footing resistance, either by ground rods or counterpoises, use of protector tubes, and, as reported by one company, fast-reclosing high-speed breakers.

Conclusions

In presenting such a voluminous mass of data as given in table II and attempting to correlate and analyze the operating records of some 150 transmission lines it is not hoped more than to touch on the salient points. The following conclusions, from the analysis made, however, seem to be justified:

1. Overhead ground wires are a very effective means of reducing line outages.

2. Placing the ground wire at excessively great heights above the line conductor does not seem to be justified.

3. Low tower footing resistance is necessary to reduce line outages due to lightning (provided lightning discharge devices such as protector tubes are not used). Values in the order of 10 ohms or less are suggested as desirable.

4. The conductor height above ground (tower height) does not appear to be an important contributing factor in affecting line outages.

5. Considerable benefit should be possible in improving the outage performance of lines by the judicious use of wood as insulation against lightning.

6. Double-circuiting a line is an effective method of reducing service outages as shown by the low ratio of double-circuit outages to total outages on such lines.

7. Effective arcing protection on insulator assemblies is desirable to reduce line troubles. Horns on the line side only do not supply such protection.

8. The generally considered means of bettering the lightning performance of lines in the 110- to 165-kv class as reported here are (1) lowering tower footing resistance, by ground rods or counterpoises, (2) protector tubes, and (3) fast-reclosing high-speed breakers.

9. The committee welcomes discussions from any of the companies who have contributed data on which this paper has been based, particularly as they may throw any further light on special features of their line construction which have affected the line performance. Comments will also be appreciated on features not possible to cover fully in answers to the committee questionnaire, or not fully covered in this presentation and discussion.

Discussion

E. R. Whitehead (Duquesne Light Company, Pittsburgh, Pa.): This paper is of special interest and value to me at this time because the company with which I am associated has just completed a rather detailed study of the lightning performance of its 66-kv transmission ring. While there are minor variations in the tower configuration a sufficiently representative one consists of a double-circuit vertical arrangement as in figure 1 of the paper. Top and bottom phases are separated 18 feet between circuits, while the middle phases are separated 22 feet. The vertical separation is 8 feet between top and middle phases and 7 feet between middle and bottom phases. The single ground wire is 7 feet above the top conductor. Six units are used in suspension and seven units for dead end. Air clearance is generally $3^1/_2$ feet.

Lightning tripouts in outages per hundred tower mile years vary from a low of 3.97 to a high of 56.8. The two sections to which these figures apply lie on opposite sides of the city, and in the past it has been assumed without question that the great differences were attributable to "preferred storm paths."

In an effort to verify this assumption, several exposed 22-kv subtransmission lines without ground wires were chosen adjacent to these 66-kv line sections and tripouts from lightning compiled in the same terms over a five-year period. The figures are 61 and 70, respectively. It is apparent that "preferred storm paths" will not account for the great difference in performance.

Since the study was primarily directed toward the improvement of poorly performing line sections, the worst of these, 28.36 miles in length, was selected together with an adjacent section 15.08 miles long and 32 towers chosen at random for ground resistance measurements. Here again it had been tacitly assumed that the poor performance could be explained by the storm frequency and very high ground resistances. The belief in the presence of high tower footing resistances arose from an earlier survey which included measurements of ground rods disconnected from the towers.

Footing resistances from 1.6 to 78 ohms were measured, the average being 16 ohms. Calculations based upon this average resistance and upon perfect ground-wire shielding gave an over-all flashover figure of 4.25 per cent. The actual flashovers for this section average 11 per year, requiring the absurd total of 260 strokes to the tower line per year. As previously stated, exposed 22-kv lines in the same general area had an outage record of only 70 per hundred miles per year. From this sample, taking into account the relative heights of the 66-kv and 22-kv lines, it has been estimated that the actual number of strokes to the 28.36-mile 66-kv line section was approximately 32.

The first step toward more accurate analysis was the construction of a tower-footing-resistance distribution table from the field data and the recalculation of the over-all flashover percentage. This calculation included midspan flashover for midspan stroke tower flashover for midspan stroke, and tower flashover for tower stroke. The result in this case was 12.45 per cent. It is clear that average ground resistance is not at all a suitable datum upon which to base estimates of line performance, nor can one easily correlate the data in the present paper with calculations. Using this percentage and assuming perfect shielding, the required number of strokes to the line is 88. This figure is still more than double a reasonable number.

The second refinement was an attempt to evaluate the effect of the electrostatically induced potential on the line wire. As has been pointed out,[1] the effect is to lower the tower-top potential necessary to cause insulation flashover, and the per cent flashovers will increase correspondingly.

An approximate method was derived to include this effect by considering a cloud height of 1,000 feet, rectangular bound charge of 2,000 feet length, a lightning cur-

rent of $^1/_{30}$ microsecond, and discharge increments of one microsecond each. At the point of stroke the maximum induced voltage is proportional to the stroke current, and a fixed constant of proportionality may be added to the tower footing resistance when solving for the current required to cause flashover. The result of this approximation was to increase the per cent flashovers to a value of 15.0.

With such a small increase attributable to the effect of induced voltage on the line wire, it was felt that the assumption of perfect shielding was invalid.

If X is the fraction of total strokes which strike a line conductor, then we may define the "shielding factor" as $(1 - X)$ and the equation governing flashovers is

$$Xn + (1 - X)Pn = F$$

where

n = total strokes to tower line
P = per cent flashovers for complete shielding
F = flashovers

Inserting

$$P = 0.15 \qquad F = 11 \qquad n = 32$$

in this equation, there is

$$0.85X + 0.15 = \frac{11}{32} = 0.344$$

$$0.85X = 0.194$$

$$X = 0.228$$

Shielding factor $= 1 - X = 0.772$, a value which has been deduced as the shielding efficiency of the Glenlyn-Roanoke 132-kv line which has a single ground wire.[2]

In order to test this analysis further, a number of tower-footing-resistance measurements were made on the line sections having the best performance. All values were under ten ohms, and since the distribution curve was taken in ten-ohm steps, this value was used to compute comparative performance of these sections.

The results were:

Line	Average Flashovers per Year	
	Actual	Calculated
Colfax-North	3.5	3.70
Colfax-Pine Creek	1.4	1.67
Pine Creek-North	3.0	2.29
B. I.-Woodville	1.7	2.01
Woodville-Dravosburg	1.8	2.23

With one exception, the calculated faults are in excess of the actual as would be expected when Megger resistance values are used instead of the surge values which are somewhat lower. Moreover, some subnormal insulation and clearances may exist on this line.

It appears that the effect of induced line voltage would be negligible on most of the lines whose performance is reported in the paper, but if shielding were generally of the order of 0.75 for single-ground-wire lines it should be evidenced by components independent of ground resistance in the curves of figure 19. Because of the absence of this component, one is tempted to conclude that practically complete shielding exists for the great majority of lines listed.

A partial explanation of this apparent disagreement may lie in the fact that while the ground wire on our lines is 7 feet above the top conductor on the drawing, it has been found as low as $31/_2$ feet above the top conductor in numerous instances because of the substitution of suspension towers for strain towers. The exact proportion of these cases is unknown at this writing.

For the transmission engineer who contemplates reconstruction of old lines to improve lightning performance the question of shielding and its numerical measure is of paramount importance, and the writer will welcome any comment which the authors of the paper may make with regard to this point.

REFERENCES

1. Discussion of PROTECTOR TUBE APPLICATION AND PERFORMANCE ON 132-KV TRANSMISSION LINES—II, **Philip Sporn** and **I. W. Gross**, by **L. V. Bewley**. ELECTRICAL ENGINEERING, September 1938.

2. Discussion of LIGHTNING INVESTIGATION ON TRANSMISSION LINES—V, **Lewis** and **Foust**, by **S. M. Zubair**. ELECTRICAL ENGINEERING, March 1936, page 277.

S. K. Waldorf (Pennsylvania Water and Power Company, Baltimore, Md.): In item 26*A* of table II of the paper are given data on the Safe Harbor-Perryville Line of the Pennsylvania Water and Power Company. The single case of burned-down conductor and prolonged outage on this line was due to sleet, and not to lightning. An additional year of operation without outage of this line has been obtained since the data were submitted to the committee, making four years in all.

In the committee's report an attempt has been made to evaluate the benefits to be derived from various factors which enter into lightning protection, such as overhead ground wires, insulation level, etc. As the committee has pointed out, it is very difficult to determine the influence of any one factor upon performance. For instance, in figure 17 of the paper, showing the effect of ground wire height on line outages, the points are widely scattered, indicating that there are other factors which are probably more important than this one item. However, in figure 19, showing the effect of tower footing resistance on line outages, the behavior of lines having counterpoise is shown to be definitely superior to those having ground rods. It should be noted that these data do not indicate any special benefits due to counterpoise other than as a means for reducing tower footing resistance, but they do indicate that tower footing resistance is a powerful factor in lightning protection.

In figures 10 to 15, inclusive, are given a number of general arrangements for counterpoise. The arrangement which has been most effective on the system of the Pennsylvania Water and Power Company has been a graded installation scheme where the number and length of counterpoise conductors have been varied to suit individual tower grounding conditions. It was on the Safe Harbor-Perryville 132-kv line that the first extensive use of this scheme of counterpoise installation was made by the Pennsylvania Water and Power Company. On this line as many as eight conductors in parallel were used as a counterpoise system connected to towers having high footing resistances initially. In such cases four geometrically and electrically parallel conductors were installed along the right-of-way on each side of a tower. Based on experiments in the field, later practice has been to limit counterpoise conductors to six in parallel, three conductors on each side of a tower. Where it has been necessary to install three parallel conductors, they have in many cases been extended to the adjacent towers and the wire used in this way rather than in adding a fourth wire.

Figure 16 indicates a superiority of two overhead ground wires over one overhead ground wire. During the past lightning season, the Pennsylvania Water and Power Company has had the opportunity of comparing the operation of two 69-kv lines of very nearly identical characteristics except as regards the number of overhead ground wires and their position. These two lines are the Holtwood-York line, 22.8 miles long, with two overhead ground wires 10 feet above the topmost line conductors at all towers, and the Holtwood-Coatesville line, 29.4 miles long, with a single overhead ground wire $31/_2$ feet above the topmost line conductors at strain towers and $71/_2$ feet above at suspension towers. Before the installation of counterpoise, the average tower footing resistances were within one ohm of each other at 133 ohms and after the installation were again within the same limit, but at 9 ohms. The Holtwood-York line has been operating for three years since improvements were made, and has had an average of 2.9 outages per 100 miles of line per year. The Holtwood-Coatesville line has operated for only one year since improvements were made, with one outage occurring, making an average of 3.4 outages per 100 miles of line per year. Although the limited period of operating experience makes it still too early to draw any conclusions, the similar behavior of these two lines indicates that the shielding provided by a single overhead ground wire may be better than heretofore has been believed to be the case.

Examination of the data on the relative frequency of single-circuit and double-circuit outages shows that on those lines having a large number of double-circuit outages, the high values of tower footing resistance are probably the principal cause of the poor performance.

The committee has not found any great dependence of performance upon insulation level. Perhaps a partial explanation of this conclusion is that the insulation level varied no more than about in the ratio of 5 to 3 whereas the footing resistances varied as much as 20 to 1. Variations in the latter factor probably obscured any effects of variation in the former. Lewis and Foust pointed out in 1934 that flashover of shielded lines occurs only when the product of tower footing resistance and tower lightning current exceeds the insulation level of the line. Experience in ensuing years has shown this to be essentially correct, which establishes the close relationship between line insulation and lightning performance.

When tower footing resistances are high, no reasonable amount of insulation will protect against flashover. Data from lines in this classification will show no effects of

line insulation upon performance. Analysis of some data available on 19 110-kv steel-tower lines, 787 miles long; 5 132-kv steel-tower lines, 263 miles long; and 9 110-kv wood-pole lines, 460 miles long, all with overhead ground wires, other than those given in the paper, shows a more definite benefit due to increased line insulation. In the 110-kv class, steel lines having six insulator units in strings showed an average of 40 interruptions per 100 miles of circuit per year, those with seven units showed 10.9 interruptions, those with eight units had 5 interruptions, and those with nine units showed 2.2 interruptions. On 132-kv steel lines, those lines with 9 insulator units in strings experienced 21.1 outages per 100 miles of circuit per year, those with 11 units showed 2.8 outages, and those with 12 units, 2.1 outages. Thus, this study showed a decided benefit due to increased insulation on steel-tower lines, but the benefit is probably more apparent than real, because no account was taken of variations in footing resistance when classifying the data. With wooden construction, the investigation showed that on 110-kv lines the outages per 100 miles of line per year were 3.7 with six insulator units, 7.3 with seven units, and 7.2 with eight units. Apparently the effect of the wooden insulation in series with the porcelain masks the effect of the increased number of insulator units, in addition to any uncertainties introduced due to neglecting the effect of tower footing resistances.

In conclusion 7 it is stated that arcing protection on insulator assemblies is desirable to reduce line troubles. It would seem more logical on lines having overhead ground wires to use the money for improving grounding conditions, rather than for arcing protection, and thus greatly reduce the number of flashovers. With modern high-speed switches, severe burning of conductors is rare.

Line 3*A* in table II shows a considerable number of double-circuit outages but no single-circuit outages over a period of ten years. This behavior is most unusual and some reasonable explanation for it would be valuable. In this report the committee has tried to segregate the effect of the various means employed to reduce lightning outages on transmission lines. In making such a segregation the results of necessity must be more or less inconsistent as the three factors; overhead ground wires, insulation, and tower footing resistances, are interdependent. Each one is dependent on the other two for its proper functioning in this scheme of protection.

E. W. Knapp (Shawinigan Water and Power Company, Montreal, Que., Canada): The committee responsible for the collection and preparation of the data incorporated in this paper are to be congratulated on the concise and clear manner in which the wealth of information has been presented. A study of the general situation brings to mind a few additional points which might prove of interest.

The system which I wish to discuss consists of two double-circuit steel-tower lines 86 miles long on the same right-of-way. The lines are operated at 110 kv, and have seven units of insulation. Lines *A* and *B* have two overhead ground wires while lines *C* and *D* have no overhead ground wires. An analysis of the lightning outages during the past ten years reveals the data shown in table I of this discussion, based on outages per 100 miles of line per year.

Table I. Lightning Outages, 1929–1938, Inclusive

Single Line Outages					Double Line Outages		
Overhead Ground Wire		No Overhead Ground Wire		Total	Overhead Ground Wire	No Overhead Ground Wire	Total
A	B	C	D		A/B	C/D	
0.93	0.82	0.23	9.3	11.2	2.8	4.3	7.1
8.3%	7.3%	2.0%	83.4%	100%	40%	60%	100%

There are three points of special interest:

1. The line farthest away from the overhead ground wires suffered the most lightning outages.
2. The two lines without overhead ground wires suffered the greater number of double line outages.
3. There was a greater percentage of double line outages on the lines with overhead ground wires, although the total outages were considerably lower.

Philip Sporn and I. W. Gross: Mr. Whitehead's method of analysis to determine lightning outages on existing lines is quite interesting, and if experience continues to bear out the close relation between actual and calculated values, it should be a method decidedly helpful in predetermining the lightning performance of new lines before they are actually constructed and placed in service.

As Mr. Whitehead points out, the matter of shielding, that is, keeping lightning off the phase wires, is most important since it is quite apparent that no matter how low the tower footing resistance is, it will not be effective in preventing flashover if the stroke terminates on the line wires rather than the ground conductor. This subject well warrants further study and confirming field data.

Mr. Waldorf has drawn the conclusion (apparently based on figure 19) that "the behavior of lines having counterpoise is shown to be definitely superior to those having ground rods." While this appears to be a reasonable deduction, if the data of figure 19 only are considered, it will be noted in referring to table II that only four of the lines out of some 150 have counterpoises throughout 30 per cent of their length or over. Mr. Waldorf's 26*A* line, which has counterpoise for 93 per cent of its length, he reports as having no outages in four years. It will be noted that this line has an average structure ground resistance of 11.4 ohms. On the other hand, line 21*E*, which has counterpoise for 38 per cent of its length, with an average structure footing resistance of 10 ohms, shows 9.8 average outages per hundred miles of line per year. Line 15 *I* having ground rods only for 56 per cent of its length has an average structure resistance of 10 ohms and a yearly outage record of 0.9 per hundred miles of line. While it may be true that a reduction of tower footing resistance to a given level by counterpoises will result in less line outages than a similar reduction by the use of ground rods, it does not appear from the data which have been presented in table II that such a conclusion is wholly justified.

The specific cases mentioned by Mr. Waldorf, one where two ground wires were used and one where only one was used indicating the same relative order of line performance, he has interpreted as indicating that one single overhead ground wire may be giving far better shielding than generally believed. The summarized data in the paper tend to lend weight to this point of view, although as pointed out in the paper, the data in many cases are not complete enough to show definitely the influence of other factors such as number of insulators, line spacing, lightning territory, etc.

The citation by Mr. Waldorf of outages on steel-tower lines as affected by the number of insulator units tends to show some benefit by increasing the number of units from six to nine. This, of course, is an increase in insulation of 50 per cent between extreme limits of insulation. As he has clearly pointed out, it is necessary to take into consideration all of the lightning protective features of the line before definite conclusions can be drawn on the merits of any one influencing factor. An attempt to analyze data of this kind, as well as that given in table II of the paper, requires a rather detailed study of many of the line characteristics before any hard and fast conclusions can be drawn.

Mr. Waldorf suggests the improvement of ground resistance on a line with overhead ground wires, in place of supplying arcing protection, and we are in thorough agreement with this statement where modern, high-speed breakers clear the fault; and, in fact, in recent lines on our own system, we have eliminated the arcing protection where high-speed breakers are used. Where slow line relaying, however, still exists or is a necessity as a result of system operation, arcing protection may still be desirable.

In referring to line 3*A* in table II, we are inclined to believe that the absence of single-circuit outages in the reported figure of 35.5 outages per hundred miles of line per year is due to the absence of a breakdown of the total outages for the ten-year period. The figures are reported as received, but, as pointed out by Mr. Waldorf, they may well be questioned.

In conclusion, it is not expected in attempting to analyze the mass of data such as given in table II that all the various factors can be definitely evaluated. It was the hope of the committee in submitting this report to collect sufficient authentic data on a large group of lines in the country so that careful analysis might show the trends in the construction and the general experience in the operation of such lines under lightning conditions.

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Industrial Notes

Capacity of U. S. Water Power Plants.—The total installed capacity of water power plants of 100 or more horsepower in the United States and outlying territories on January 1, 1939, was 18,093,726 horsepower, according to a recent announcement of the Federal Power Commission. The United States total was 17,948,906 horsepower, an increase of 4 per cent over the previous year. The report shows that 88 per cent was installed in electric utility plants and the balance in industrial and miscellaneous plants.

Large Turbine Contracts Awarded.—The Federal government has recently awarded contracts amounting to $1,843,200 to the Allis-Chalmers Mfg. Co. for power machinery, including 4 turbines of 103,000-hp capacity, to be installed at Shasta Dam of the Central Valley (Cal.) reclamation project. A contract for two smaller turbines was awarded to James Leffel & Co. of Springfield, Ohio, for $68,055.

Okonite Promotions.—Charles M. Kirkland was recently elected secretary of The Okonite Co., at Passaic, N. J., and the Okonite-Callender Cable Co., Paterson, N. J. He was formerly engaged in sales work with the company in the Chicago territory. F. J. Dahleiden has been appointed manager of the newly established Okonite district office in the National Building, 1404 E. 9th St., Cleveland. He was formerly sales engineer in the Chicago territory.

Power Sales Increase in N. J.—Improvement in industrial conditions in the first four months of this year, as compared with the first four months of 1938 is indicated by the increased consumption of electric power and gas fuel by manufacturing and other business enterprises in the New Jersey territory served by Public Service Electric & Gas Co. Electric power sales increased 16.26 per cent and sales of gas for industrial uses were up 13.5 per cent. The company furnishes electric power to 94 per cent of all industries in its territory.

Increased Appliance Sales.—Household washer shipments in April continued their advance over 1938, aggregating 116,199, or 22.11 per cent more than the total, 95,158, reported for the same month a year ago. It was the sixth consecutive month showing an increase above the same period a year before. April ironer shipments totalled 9,047 compared to 7,111 a year ago, an increase of 27.23 per cent. Ironers shipped in the four months were 36,878 compared to 37,628 in the same period of 1938.

Cramer Company Moves to Connecticut.—The R. W. Cramer Co., Inc., formerly located at 67 Irving Pl., New York City, has moved into its new plant located in Centerbrook, Conn. A New York sales office in charge of R. C. Heyl, a vice-president of the company, will be retained at the old location. This company has been for many years the United States distributors of Sauter time switches, a Swiss product. In the new plant they will also manufacture the Cramer running time meters and a new complete and diversified line of electric timers.

Walker Electrical Co. Appointment.—T. J. Fleischer, formerly connected with the Crouse-Hinds Co., has been appointed general sales manager of the electrical manufacturing division of the Walker Electrical Co., Atlanta, Ga. The company is erecting a new plant in Atlanta's northside section, for the manufacture of a complete line of outlet boxes and accessories.

New Plant for Carboloy.—The new $750,000 plant and general offices of the Carboloy Co., Inc., at Detroit, Mich., a General Electric subsidiary, was formally opened on June 1 for the manufacture of masonry drills for drilling holes in all non-metallic construction materials and other cemented carbide products. This new structure, the largest cemented carbide plant in the United States, embraces a total area of 121,750 square feet.

Trade Literature

Varnished Insulation.—Bulletin, 28 pp. Describes varnished cambric and tape of various types; varnished insulating silk, paper, canvas and duck, tubing, fiberglas, transformer leads, etc. Irvington Varnish & Insulator Co., Irvington, N. J.

Tong Test Ammeter.—Bulletin 400, 6 pp. Describes the various types of Crompton Tong Test ammeters for instant a-c or d-c current measurements on bare or insulated conductors without breaking the circuit. Columbia Electric Mfg. Co., 4525 Hamilton Ave., N.E., Cleveland, O.

Measuring Bridge.—Bulletin 620. Describes the "Dwarf" measuring bridge for measuring resistance in the field, factory and laboratory. Advantages include a wide range, simple manipulation, high sensitivity and light weight. Herman H. Sticht & Co., 27 Park Pl., New York, N. Y.

Insulated Cables.—Bulletin 2007 A, 8 pp. Describes the advantages and applications of "Okolite" insulated cables for high voltage circuits; includes comparative curves of the operating efficiency, greater load carrying ability and moisture-resistance. Additional data is given on installation methods, tests and available designs. The Okonite Co., Passaic, N. J.

World's Fair Automatic Substation.—A bulletin (No. 3905) issued by the I-T-E Circuit Breaker Co., 19th & Hamilton Sts., Philadelphia, Pa., describes the new, completely automatic World's Fair substation of the Interborough Subway System, New York City. Included is a colored map of transportation routes, both rail and road from the metropolitan area to the World's Fair; also an invitation to all Fair visitors to participate in inspection trips to the new substation.

Plastics.—Bulletin 1518 B, 16 pp., "A Business Man's Guide to Modern Plastic Materials." Profusely illustrated, this bulletin covers the wide applications of Bakelite molding and other materials throughout all industries, including the electrical field. Bakelite Corp., 247 Park Ave., New York.

Wood Preservation Equipment.—Bulletin 1834, 32 pp., "Machinery for Wood Preservation." Outlines the history of wood preservation, types of preservatives used in modern treatment, methods and processes, and types of machinery used. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Concrete for Buildings.—Bulletin, 40 pp., "Concrete for Industrial Buildings and Garages." Contains a comprehensive description of structural layouts and details, mechanical installations, and alterations in concrete buildings. Numerous drawings, sketches and photographs are included. Portland Cement Association, 33 W. Grand Ave., Chicago, Ill.

Recording Voltmeter.—Bulletin 538. Describes a new, round-chart, portable recording voltmeter, built especially for survey work. A self-contained instrument enclosed in a waterproof case, it is designed for indoor or outdoor service and equipped for adjustable mounting legs for pole or wall mounting. The Bristol Co., Waterbury, Conn.

Motor Maintenance Equipment.—Catalog, 84 pp. Describes a complete line of portable equipment for maintenance of commutators and slip rings; motor repair equipment; variable speed transmissions; cleaning equipment; soldering tools; testing and recording devices, etc. Sections are devoted to care of electrical equipment of various types, electrical terms, wire tables, etc. Ideal Commutator Dresser Co., Sycamore, Ill.

Testing Equipment.—Catalog AE11-a. Describes a new "Hipot" insulator and bushing tester for testing by the voltage gradient method and which indicates location as well as extent of faults. The improved device employs a more sensitive instrument, has a changeover switch for high and low voltage, special prongs and leather carrying case. Catalog AE11-b covers new applications of the "Hipot" Potential Indicator, which includes furnishing a continuous line to ground voltage indication; use as an indicator of synchronism or to synchronize two or more lines; for operating relays for signal purposes; and line to ground fault indication or relaying. Roller-Smith Co., Bethlehem, Pa.

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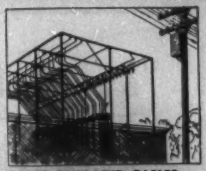

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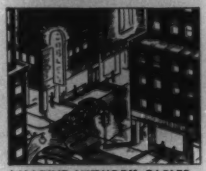

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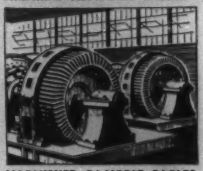

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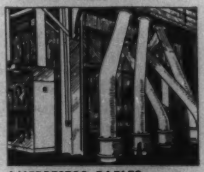

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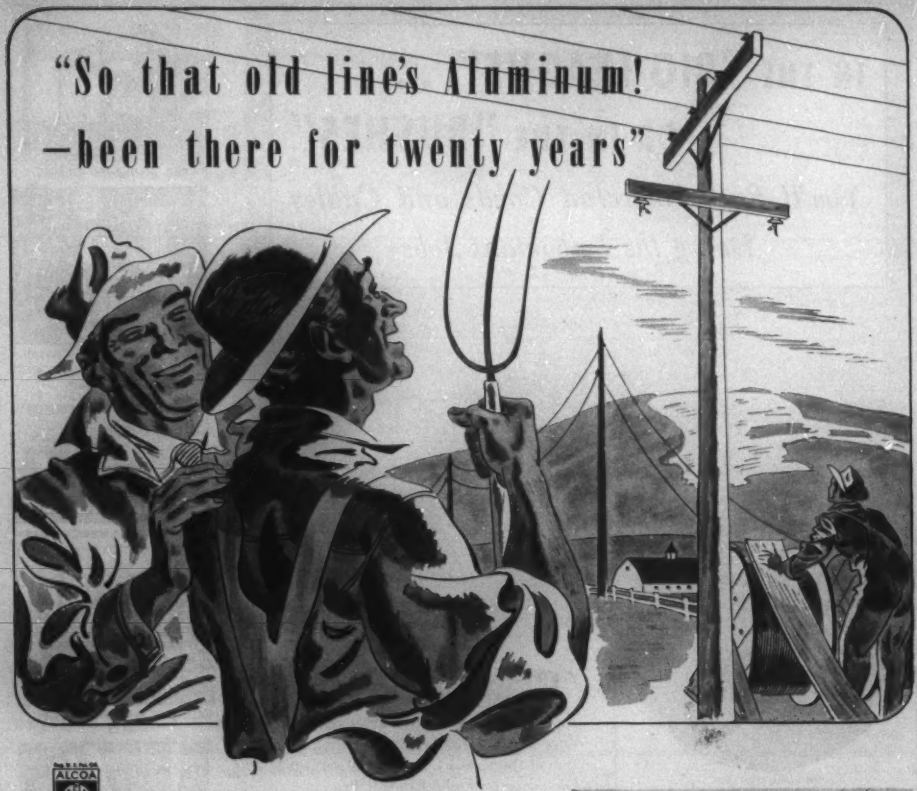

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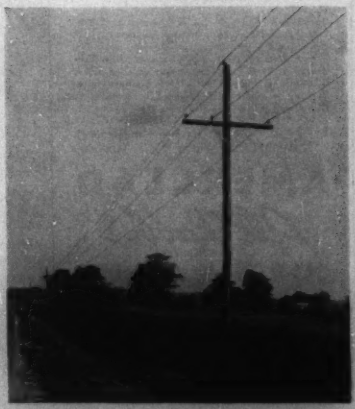

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The ideal equipment for testing insulators and transformer and oil circuit breaker bushings by the voltage gradient method. Range is 13,200 to 220,000 volts. Has many advantages over the power factor method, chief of which is indicating *location* as well as *extent* of fault.

New Catalog AE-11-a gives the details. Send for it. *Use the Coupon Below.*

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The Type C control relay has many applications, chief of which is for insertion between the contacts of a control switch or push button and the operating solenoid of an electrically operated air or oil circuit breaker or other apparatus. Available for a-c or d-c. Trip-free or non-trip-free. Very rugged. No a-c hum. All parts accessible. Simple control wiring.

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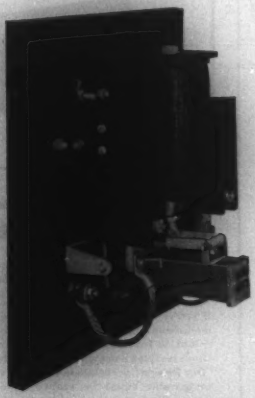

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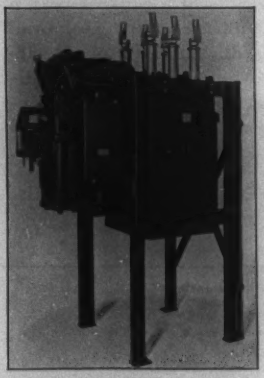
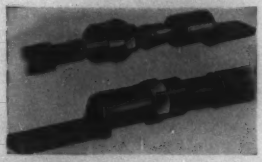
Disconnecting Switch.—In this new single pole, double blade, tandem throw, 15-kv, 600-ampere disconnecting switch, designed by the Delta-Star Electric Co., Chicago, the inside lock, combined with a common hinge and contact member at the center insulator unit, results in shorter blades and decrease in width of the current carrying parts. Both factors are important when switches are used in cubicles, cell structures and other restricted places, where available striking distance between the open switch blade and cell doors is limited. The tongue type contacts are of the line pressure type with full floating blades, plain or silvered as desired. At the hinge end of the blades are annular pressure rings. The steel base is equipped for mounting on either flat surface or $1^1/_4$-inch pipe frame.

Indoor Circuit Breaker.—A new indoor oil circuit breaker, widely applicable to central station and industrial service, has been introduced by the Boston works of the Allis-Chalmers Mfg. Co. Designated as type



KDZ-40, the breaker is of particular interest because its horizontal axis (a line drawn through the center of each pole) is perpendicular to the operating mechanism. This arrangement of the bushings eliminates the necessity of crossing the leads in certain applications of open and enclosed type switchboards. For the same reason, it is adaptable for replacing obsolete breakers of the same arrangement, as existing bus and feeder connections may be retained. The type KDZ-40 is equipped with "Ruptors" to give efficient interruption of short circuits along with low arc energy, low pressure and a minimum of oil deterioration. It is furnished for 600 and 1200 amperes at 15 kv and 2000 amperes at 7.5 kv; interrupting capacity rating 100,000 kva; arranged for flat surface mounting—in cells, switchhouses, cubicles, metal-clad switching equipments, etc.

Connectors.—The Burndy Engineering Co., 459 East 133rd St., New York City, has announced a line of Hood-Nut connectors for use with rubber or compound insulated cables at points where these conductors are joined to other types of cable or to switches, cutouts, etc. In using these connectors, taping is done from the shroud of the nut to the rubber insulation of the cable. In this manner, moisture is prevented from entering between the insulation and the conductor, thereby prolonging the life of



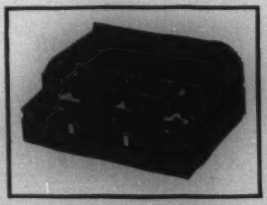
the insulation. The braid is peeled back beyond the tape to avoid "wick effect" which might draw up moisture beneath the tape. In addition to terminal type ZAK illustrated, Hood-Nut connectors are also furnished in the form of T-connectors, straight connectors and in special forms.

Gear Motor.—A new vertical "Syncro-gear" unit type GDV, has been specially designed by U. S. Electrical Motors, Inc., Los Angeles, Calif., to meet conditions peculiar to vertical operation. The unit incorporates a small, geared, oil pump, which forces an ample oil supply to bearings, gears and pinions.

Wire Wound Resistors.—A new line of wire wound resistors has been made available by Consolidated Wire & Associated Corps., 548 So. Peoria St., Chicago, Ill. Four sizes of adjustable resistors are offered—10-watt,

25-watt, 50-watt, and 75-watt, of which the 10- and 25-watt sizes are shown with extra adjustable bands. Four sizes of wire wound fixed resistors are offered—5-watt, 10-watt, 20-watt, and 50-watt—to fill most requirements for receivers, transmitter, amplifier and industrial applications. Two mounting brackets are supplied on all but the 10-watt size in the adjustable resistors. All four sizes have two tab terminals. All four sizes of fixed resistance units have solder lugs and all but the 50-watt size have tinned copper leads as well.

• • •



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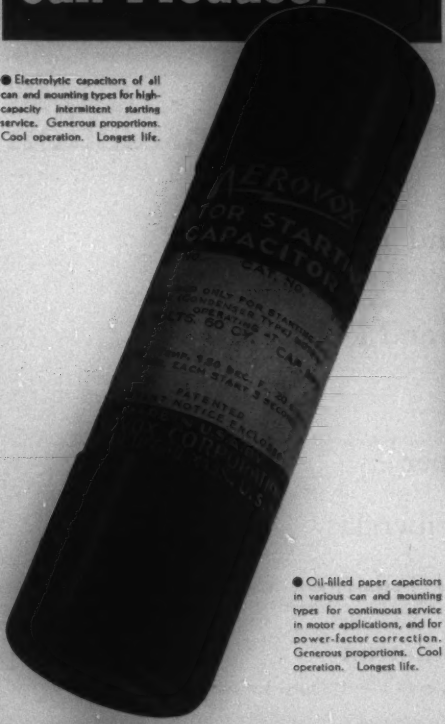

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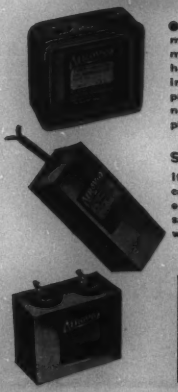

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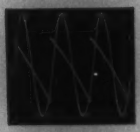
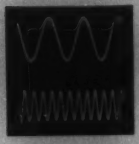


Independence and freedom from interaction of the two channels are shown in this actual oscillogram illustrates ability of the Type 185 instrument to handle a saw-tooth and sinusoid at same time, and to make them appear on one oscillograph screen.



Actual photo showing comparison of two harmonically related signals on one oscillograph, using electronic switch. Patterns may be displaced as shown for individual observation.

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Type 185

●Switch rate variable from 6 to 2000 times per second. Handles extremely low- and high-frequencies. Permits superimposed patterns for matching or accurate comparisons, or the displacement of patterns of simultaneous phenomena for close observation of either one. Also provides square-wave generator, completely covering the range from 60 to 400 cycles, per second.

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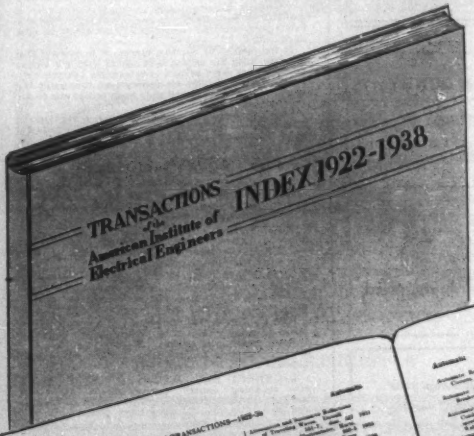
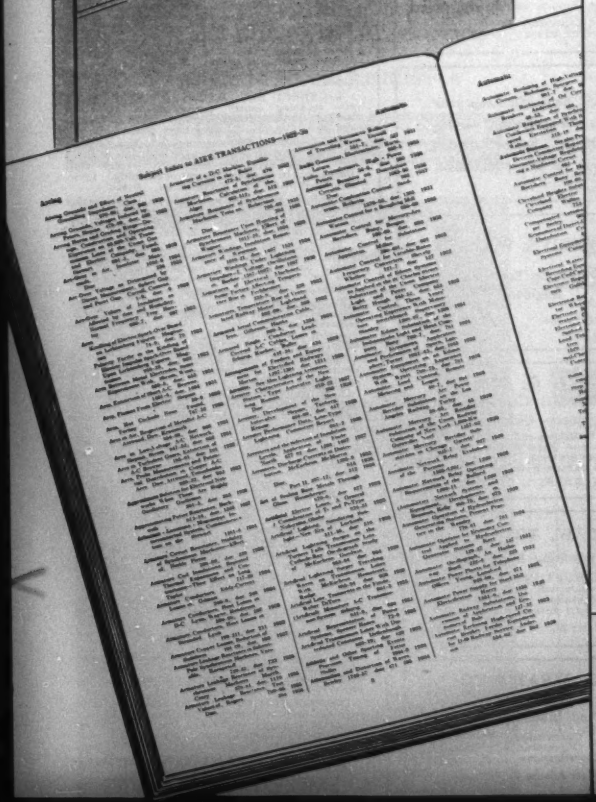
of the AIEE TRANSACTIONS from 1922 to 1938 Inclusive





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2. Author Index. Every author or co-author of a technical paper or discussion published in the TRANSACTIONS during the 17 years covered by the Index is listed alphabetically in this section. The 11,000-odd entries give direct page reference to each paper and each published discussion.

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B.S.E.E., married, 34, Univ of Wash, '30, with honors. Exper: 6½ yrs tel eqpt devpmt, 2½ yrs water supply and pressure irrigation systems. Desires eqpt application work. E-464.

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ELEC ENGR, 44, married. Exper all kinds tests, installing apparatus, maintenance network system, meters and relays; 12 yrs dept supt. Desires connection with util. Locate anywhere. E-463.

LICENSED ELEC ENGR, 34, MSEE, pub util and teaching exper; competent in statistical work, graphs and draftg, preparation of tech reports and articles; desires supervisory pos which will utilize abilities. E-465.

B.E.E., 1937 from B.P.I., age 23, eligible M.E.E., 1940; 2 yrs exper elec-mech des, devpmt, test. Desires pos in research, devpmt or teaching. Location, East preferred. Excellent ref. E-453.

B.S.E.E., 1938, single, 27; 2 yrs exper service field on all types elec eqpt. Desires pos in the service field or maintenance of elec eqpt. Avail immed; will go anywhere. E-454.

M.S.E.E., '38, A.B. '36, Columbia Univ, 25, single, Tau Beta Pi. One yr elec lab asst, Columbia Univ. Salary secondary, available immed, excellent ref. Location NY and vicinity preferable. E-459.

B.S.E.E., 1937, V.P.I., A.B. 1935, 27, single; 20 mos exper REA line des and constr. First class radiotel operator's license; 11 yrs amateur radio operator and service work. Location immaterial. E-461.

B.S.E.E., '38, Univ. of So. Carolina, single, 22, desires jr engg pos; location immaterial. Salary secondary. E-462.

B.S. 1935; will obtain E.E. 1939, Newark Col Engg; single, 24; exper: 2 yrs electronics industries; 2 yrs teaching elec engg subjects. Desires pos above or allied fields. E-466.

UNIV OF COLO '38, B.S.E.E., Eta Kappa Nu, 22, single. Prefers pos in com field; util or mfg considered. Location immaterial. Available immed. E-467.

B.S.E.E., 1936, 23, single. One yr steel mill constr, 1½ yrs pwr station constr, control and relay checker. Desires pos elec util—system protection, planning, oprn. Any elec constr. Knows radio. Location immaterial. E-468.

E.E., B.S., '35, M.S. '36, married, 26. Exper ltg, draftg, estimating, ordering materials, costing. Desires oprn, maintenance, constr or mfg work with future. Hard worker. Available immed. Location, NY. E-469.

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Fact is, a considerable part of the money you pay us for telephone service goes right out in taxes.

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In 1924 this chestnut pole required replacement or salvage because of ground-line decay. The Williams Pole Mount salvage method was employed. Today the pole appears sound enough for another 15-year period. Equivalent Williams Pole Mount construction now would cost from $38.00 to $40.00 for grouped jobs to about $45.00 for single poles—with some extras for freight beyond 200 miles and for transportation to relatively inaccessible pole locations.

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Figure against the above the cost of replacement of pole otherwise required in 1924 to carry trolley feeders, telephone and light and power services with riser pipe, and question whether that replacement would last until 1950. You then have the answer as to which method is cheaper. About 7,000 successful installations in United States and Canada prove we have an economic salvage construction device and method. Used also to support new poles to meet special anchorage conditions requiring development of full strength of pole.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
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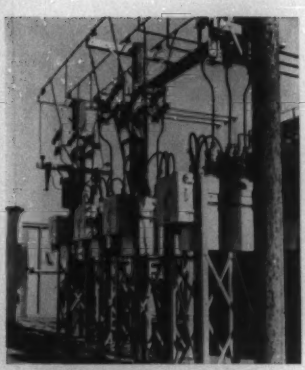

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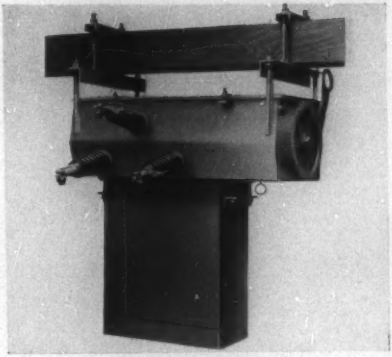

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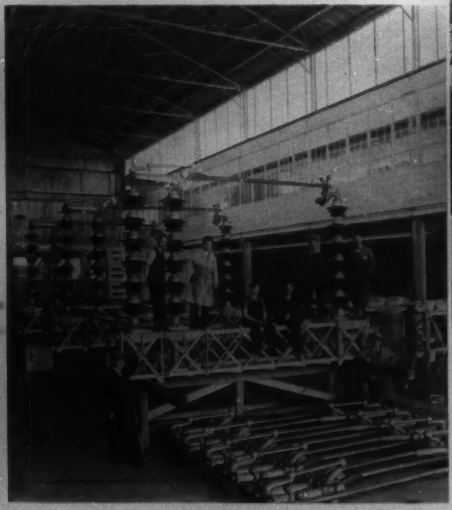

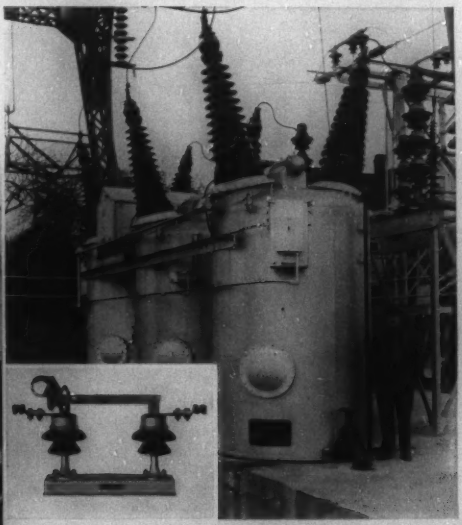

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Founded 1878

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